NATIONAL CONVENTION TRANSACTIONS 1956

TENTH ANNUAL CONVENTION

AMERICAN SOCIETY FOR QUALITY CONTROL

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FOREWORD

This year marks the tenth anniversary of the founding of the American Society for Quality Control. It is well that we pause briefly at this time to review developments of our first decade.

During the early years of the Society, its greatest strength lay in the Sections and Regional organizations, most of which antedated the formation of the national organization. The first four national conventions were held in conjunction with regional conferences.

Bound Transactions were published in connection with the first national convention held at Chicago in 1947. The speakers' papers were subjected to editorial review. For the sake of typographical uniformity they were all retyped by the printer before being photographed for printing. This proved to be such a prodigious task that the committee recommended it never again be undertaken in that fashion.

There was no publication of papers at Rochester in 1948. A bound volume of abstracts was published at Boston in 1949. The ten papers presented at Milwaukee in 1950 were printed and sold as separate papers.

The first national convention to be held independent of any regional conference was in 1951 at Cleveland. The convention committee wanted to restore the practice of publishing a Transactions. In order to eliminate the difficulties experienced earlier, it was decided to eliminate editorial review and to provide the authors with sufficiently detailed instructions for the preparation of their manuscripts that they might be photographed directly for printing. Under that policy, bound Transactions were published in 1951, and have since been published in 1952 at Syracuse, 1953 at Philadelphia, 1954 at St. Louis, 1955 at New York, and the current volume at Montreal in 1956.

On the immediately following pages we present a "Ten Year Index to National Convention Transactions." We make no claim to have properly classified every paper. Most papers were fairly easy to classify under some one heading. Others are listed under more than one heading. Still others were so unusual in their subject matter as to almost defy classification. We hope this feature will be useful to you and would appreciate your comments on it.

This year for the first time we present several papers in a foreign language. Two of the speakers are from France and four of the Canadian speakers will present their papers in the French language. One of these papers was available in French only, one in English only and the other four are reproduced here in both French and English. In addition, the introduction to the French sessions by one of our Vice-Presidents, Dr. Julian H. Toulouse, is presented in both French and English.

Also for the first time, we present this year a list of the books on display at the Book Booth. This list is included in these opening pages.

Request for permission to reprint any portion of these Transactions should be addressed to Professor Mason E. Wescott, Chairman, Editorial Board, University College, Rutgers University, New Brunswick, New Jersey.

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Edward M. Schrock
National Transactions Chairman
General Convention Committee

TEN YEAR INDEX TO NATIONAL CONVENTION TRANSACTIONS: 1947 - 1956

The numbers following the years are the pages upon which the papers indexed begin. For example, there are two papers in the Transactions for 1947 that are about Administrative Applications, and they start on pages 111 and 193.

There was no publication in 1948. The 1949 publication consisted of abstracts. In 1950 there were ten papers separately bound and numbered from one to ten. The listings for this year are therefore the number of the paper. The listings for subsequent years are all page numbers.

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PAPER STUDIES IN CATALYTIC CRACKING

C. T. Shewell
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Catalytic cracking units, whether of the fixed bed or fluidized bed type, are major processing units in nearly all modern refineries. It is here that heavy distillates and residuums are upgraded from fuel oil components to heating oil, gasoline, and petrochemical components. The value added to the material by such catalytic cracking is so large that operation of plant scale units at inefficient conditions cannot be tolerated in today's competitive market.

Over the years, various groups have developed correlations, applicable to their particular type of cracker, which relate the prime independent operating variables to the yields and qualities of the products from their operations, and it is now possible to crack, on paper rather than in an actual plant unit, any available charge stock. This is quite obviously the cheapest experimental method of determining optimum operating conditions for a given installation.

In the oil industry, rather violent price fluctuations are not uncommon, and as the impact of these price changes hits the refiner, he must be ready to change his operations so as to remain at optimum under this new set of prices, whether the new optimum represents more or fewer dollars than the old optimum. In order to find where any optimum lies, it is necessary to explore the response surface of the operation and apply the current price structure to the feed and products at a number of different operating conditions. This paper will illustrate such a process as applied to a fluid catalytic cracking unit in a large refinery.

The mere fact that one is interested in an optimum set of operating conditions presupposes that the response surface, in operating space, is not planar, and, hence, the second order designs of Box and Hunter are of the types necessary to define the response surface. A tacit assumption is made that the surface is well behaved, that is, not crumpled nor exhibiting more than one maximum in the area of interest.

On a going operation, it is usually sufficient to center design space at current conditions and choose design units on all independent variable axes so that the response to a change of one unit on any axis is nearly equal to the response change brought about by a unit change on any other axis. This is largely a matter of convenience, so that one may look at the various coefficients and easily pick out the important variable, without having to worry about unequal scales. If it happens that current conditions are at one or more operating limits, then it is best to back off and place the design center at such a location that the extreme data positions called for by the design are at the limits of operability for those particular variables. Only very seldom should design space cover more than a small (25% or less) portion of operating space. The case of a new charge stock is one that may be cited as an example where design and operating space have the same limits. The reason for this is that the surface is only poorly defined by the equation except in the design region, and if the surface happens to be of higher order than second, only over some small region will a second order surface approximate satisfactorily this higher order surface.

For an orthogonal composite design with k factors (independent variables), the basic design has 2^k points with no confounding and has $2k + 1$ extra axial points. The distance of these axial points (α) from the design center varies with the value of k as shown in the table below:

k	2	3	4	5(1/2 replicate)
α	1.000	1.215	1.414	1.547

This is necessary to retain orthogonality, which simplifies the calculations leading to the coefficients of the second degree equation representing the response surface.

With four independent variables the design to be used is as follows, and the calculated responses for a particular price structure are in the column headed Y:

x_1	x_2	x_3	x_4	Y
-1	-1	-1	-1	344.1
-1	+1	+1	-1	345.5
+1	-1	+1	-1	344.2
+1	+1	-1	-1	346.5
-1	-1	+1	+1	346.3
-1	+1	-1	+1	348.6
+1	-1	-1	+1	341.4
+1	+1	+1	+1	348.1
-1	-1	+1	-1	344.4
-1	+1	-1	-1	349.1
+1	-1	-1	-1	341.0
+1	+1	+1	-1	346.7
-1	-1	-1	+1	344.4
-1	+1	+1	+1	348.0
+1	-1	+1	+1	345.9
+1	+1	-1	+1	345.9
$+\sqrt{2}$	0	0	0	345.2
$-\sqrt{2}$	0	0	0	345.8
0	0	$-\sqrt{2}$	0	342.9
0	0	$+\sqrt{2}$	0	344.4
0	$-\sqrt{2}$	0	0	344.6
0	$+\sqrt{2}$	0	0	350.4
0	0	0	$-\sqrt{2}$	346.8
0	0	0	$+\sqrt{2}$	348.3
0	0	0	0	347.0

One now utilizes these numbers in the usual manner to estimate the coefficients of the equation of the response surface to obtain

$$Y = 346.66 - 0.5774x_1 + 1.7451x_2 + 0.5111x_3 + 0.4611x_4 - 0.5375x_1^2$$
$$+ 0.4625x_2^2 - 1.4625x_3^2 + 0.4875x_4^2 + 0.1688x_1x_2 + 0.7563x_1x_3$$
$$- 0.0813x_1x_4 - 0.7313x_2x_3 - 0.0938x_2x_4 + 0.4938x_3x_4$$

It is extremely difficult to visualize the shape of the surface in this form, so that a transformation into the canonical form is desirable. This transformation leads to:

$$Y - 345.3231 = -1.6882X_1^2 - 0.4062X_2^2 + 0.4318X_3^2 + 0.6125X_4^2$$

and it is immediately apparent that we are faced with a saddle-shaped surface. The coordinates of the "seat" of the saddle are found by taking partial derivatives of the response surface equation with respect to each variable separately, equating each derivative to zero and solving the resulting set of four simultaneous linear equations. The equations are:

$$\frac{\partial Y}{\partial x} = -0.5774 - 1.0750x_1 + 0.1688x_2 + 0.7563x_3 - 0.0813x_4 = 0$$

$$\frac{\partial Y}{\partial x} = +1.7451 + 0.1688x_1 + 0.9250x_2 - 0.7313x_3 - 0.0938x_4 = 0$$

$$\frac{\partial Y}{\partial x} = +0.5111 + 0.7563x_1 - 0.7313x_2 - 2.9250x_3 + 0.4938x_4 = 0$$

$$\frac{\partial Y}{\partial x} = +0.4611 - 0.0813x_1 - 0.0938x_2 + 0.4938x_3 + 0.9750x_4 = 0$$

and their solutions are:

$$x_{1S} = -0.5124 \qquad x_{3S} = +0.3102$$

$$x_{2S} = -1.6320 \qquad x_{4S} = -0.8298$$

$$Y_S = 345.3231$$

The relations between the x's and the X's are:

$$X_1 = 0.3204(x_1+0.5124) + 0.1677(x_2+1.6320) + 0.9261(x_3-0.3102) - 0.1075(x_4+0.8298)$$

$$X_2 = -0.9471(x_1+0.5124) - 0.0386(x_2+1.6320) - 0.3158(x_3-0.3102) + 0.0421(x_4+0.8298)$$

$$X_3 = -0.0158(x_1+0.5124) - 0.6811(x_2+1.6320) + 0.0330(x_3-0.3102) - 0.7313(x_4+0.8298)$$

$$X_4 = -0.0090(x_1+0.5124) - 0.7117(x_2+1.6320) + 0.2038(x_3-0.3102) + 0.6722(x_4+0.8298)$$

The coordinates of the minimax ("seat") are within design space, except for x_{2S}, and it is only slightly outside at -1.6320 vs. 1.4142. This suggests that not all of the x's will be at their limits when the optimum is attained, but since we have a saddle, at least one of the x's will be at its limit.

In general, there is no strictly analytic solution to problems of this type; the optimum must be found by some species of trial and error calculation, such as using a fine meshed network of values in design space substituted into the original equation. This is easily done on an electronic computer, having it produce only answers which are larger than the maximum observed in the original design. Another method is to use the method of steepest ascents of Box starting from the "seat" of the saddle and traveling up the ridge until stopped by the operating limit on one or more of the factors. Where a two ridge system is encountered, as in this example, care must be taken that the proper

direction is used as, for example, the intersection with the left hand face of operating space might be lower than that with the right hand face on one or more of the factors. Considering only x_4, one can travel farther from the "seat" by going in a positive direction than by going in a negative direction, and, hence, this should put one higher on the ridge. Obviously, one must travel in the positive direction on x_2 in order to come within design space, since the x_{2S} value is -1.6320.

Fortunately, there is another way out for this particular problem. The original equation may be rearranged to give

$$Y = 346.6600 - 0.5375(x_1 - 0.7035x_3)^2 - 1.1965x_3^2 + 1.7451x_2 + 0.4611x_4$$
$$+ 0.4625x_2^2 + 0.4875x_4^2 + 0.1688x_1x_2 - 0.0813x_1x_4 - 0.7313x_2x_3$$
$$- 0.0938x_2x_4 + 0.4938x_3x_4 - 0.5774x_1 + 0.5111x_3$$

which shows that no matter what values one assigns to x_1 and x_3, since the coefficients of the square terms are negative, their effect will be to reduce the value of Y; hence, the equation is negative definite in x_1 and x_3.

Under these circumstances one takes the partial derivatives of Y with respect to x_1 and x_3, equates them to zero, and solves the pair of simultaneous linear equations for x_1 and x_3 in terms of x_2 and x_4, thus obtaining

$$x_1 = -0.0231x_2 + 0.0527x_4 - 0.5063$$

$$x_3 = -0.2560x_2 + 0.1825x_4 + 0.0438$$

If these values of x_1 and x_3 are now substituted back into the original equation, one gets, after a lot of algebra

$$Y = 346.7319 + 1.7130x_2 + 0.4806x_4 + 0.5542x_2^2 + 0.5304x_4^2 - 0.2181x_2x_4$$

Now, it is perfectly easy to see that the positive limits of both x_2 and x_4 will produce the highest possible value for Y in design space. Accordingly, we assign $+\sqrt{2}$ to both x_2 and x_4, and substituting this value into the above equations for x_1 and x_3, we obtain: $x_1 = -0.4643$ and $x_3 = -0.0602$; and, of course, Y = 351.6283 from the simplified equation.

Now let us examine another charge stock to this same system. The basic design and factors are identical to the previous case, but the Y values are different. Without showing the individual values, the data lead to the equation

$$Y = 343.7621 - 0.0109x_1 - 96.1441x_2 - 0.8685x_3 - 0.0893x_4 - 0.000016x_1^2$$
$$+ 14.1652x_2^2 + 0.0099x_3^2 - 0.0000089x_4^2 + 0.0856x_1x_2 - 0.000046x_1x_3$$
$$- 0.000030x_1x_4 + 0.0228x_2x_3 + 0.0016x_2x_4 - 0.000084x_3x_4$$

By exactly similar steps as used previously

$$x_{1S} = +440.3970 \qquad x_{3S} = +60.4840$$

$$x_{2S} = +1.7762 \qquad x_{4S} = +4128.5821$$

$$Y_S = +414.0264$$

and

$$Y - 414.0264 = 0.00015X_1^2 - 0.0000069X_2^2 + 0.0099X_3^2 + 14.1654X_4^2$$

and again we have a saddle, but now the "seat" is very far away from design space, and we have essentially a one factor ridge along the X_4 axis.

$$X_1 = -0.9919(x_1-440.3970) + 0.0030(x_2-1.7762) - 0.0062(x_3-60.4840) - 0.1267(x_4-4128.5821)$$

$$X_2 = -0.1267(x_1-440.3970) + 0.00032(x_2-1.7762) + 0.0035(x_3-60.4840) + 0.9919(x_4-4128.5821)$$

$$X_3 = -0.0057(x_1-440.3970) - 0.00079(x_2-1.7762) + 0.9999(x_3-60.4840) - 0.0043(x_4-4128.5821)$$

$$X_4 = -0.0030(x_1-440.3970) - 0.9999(x_2-1.7762) - 0.00081(x_3-60.4840) - 0.000058(x_4-4128.5821)$$

One is tempted to say that Y depends only on X_4 and X_4 depends only on x_2, so we should assign the value $x_2 = -\sqrt{2}$ and let the other factors go where they will, as the value of Y is insensitive to their magnitudes. One overlooks the fact that X_2 will have a value in the neighborhood of 4000, and thus $-0.0000069X_2^2$ will be around 100, which is far from negligible, and X_1 will have a value of about 800, so that $-0.00015X_1^2$ is also about 100 and cannot be ignored.

If the original equation is rearranged, one obtains

$$Y = 343.76211 - 0.000016(x_1+0.9260x_4)^2 + 0.000005x_4^2 - 96.1441x_2 - 0.8685x_3 + 0.0893x_4 + 14.1652x_2^2 + 0.0099x_3^2 + 0.0856x_1x_2 - 0.000046x_1x_3 + 0.0228x_2x_3 + 0.0016x_2x_4 - 0.000084x_3x_4$$

and although the coefficient of x_4^2 is positive, one might be tempted to again proceed as in the first case. However, this leads to

$$Y = -152.7669 + 653.1193x_2 - 0.4376x_3 - 176.6539x_2^2 + 0.0098x_3^2 - 0.4236x_2x_3$$

and it is apparent that $x_2 = +\sqrt{2}$ and $x_3 = -\sqrt{2}$ give the maximum Y = 419.0615; but the values of $x_1 = 2436.6990$ and $x_4 = 1036.8985$ which must be used are absurd.

It is apparent that a different method of attack is needed here, and the fine mesh grid is the one actually selected. The grid was set up as shown on the following page.

x_1	x_2	x_3	x_4
-1.41420	-1.41420	-1.41420	-1.41420
-1.06065	-1.06065	-1.06065	-1.06065
-0.70710	-0.70710	-0.70710	-0.70710
-0.35355	-0.35355	-0.35355	-0.35355
0.00000	0.00000	0.00000	0.00000
+0.35355	+0.35355	+0.35355	+0.35355
+0.70710	+0.70710	+0.70710	+0.70710
+1.06065	+1.06065	+1.06065	+1.06065
+1.41420	+1.41420	+1.41420	+1.41420

The calculations were performed on an electronic computer in this way: with x_1, x_2, x_3 all at -1.41420, x_4 took on the nine values listed in succession, and at each value a calculation was made for the value of Y, using the original equation of the response surface. After each calculation, the new value of Y was compared with the previous largest value obtained so far in the series, and if the new value was larger, it was stored together with its coordinates. If smaller, it was discarded, and the next value of x_4 used. After these first nine calculations, the value of x_3 was changed to -1.06065, keeping $x_1 = x_2 = -1.41420$, and again x_4 varied over the nine listed values, each answer being compared with the highest previous value of Y found so far. This process finally results in 9^4 values of Y, but only the highest ever found is retained, together with its coordinates. This sounds like a tremendous computation job, but the program was prepared in two hours, the deck checked out in one hour, and the 6,561 computations made in 35 minutes. The final answer from this procedure was

$$x = -\sqrt{2} \qquad x = -\sqrt{2}$$

$$x = -\sqrt{2} \qquad x = +\sqrt{2}$$

$$Y_{max} = 509.66$$

To recapitulate: (1) a set of independent variables is chosen which are known to affect the process in a predictable fashion; (2) a suitable second order design is chosen; (3) the basic yields and qualities are obtained for each point in the design; (4) the price structure of interest is combined with the yield-quality data to obtain the value of the process at each point in the design; (5) the economic equation of the response surface is obtained; (6) the response surface is explored for the optimum.

In order to illustrate the effect of price structure on the proper operating conditions to attain optimum return on any charge stock, the same two sets of yield-quality data examined in detail above have had three different price structures applied, and the economic response surfaces have been explored to define the optima. Case I is normal summer conditions with gasoline worth 3¢/gal. more than heating oil, Case II shows the effect of only a 1¢/gal. differential in favor of gasoline, and Case III reflects the situation when heating oil is worth 1/2¢/gal. more than gasoline. Stock A is a light product which can go directly into heating oil or be cracked, and Stock B is a heavy product which can go into fuel oil or be cracked. When the economic value of the material as cracking stock falls below its value for the alternate method of

utilization, it should be withdrawn from cracking charge stock tankage and disposed of by the alternate route.

	Stock A				
	Y	x_1	x_2	x_3	x_4
Case I	391.00	-0.35355	$+\sqrt{2}$	0	$-\sqrt{2}$
Case II	351.59	-0.35355	$+\sqrt{2}$	0	$+\sqrt{2}$
Case III	338.36	-1.06065	$+\sqrt{2}$	-1.06065	$+\sqrt{2}$

	Stock B				
	Y	x_1	x_2	x_3	x_4
Case I	419.44	$+\sqrt{2}$	$+\sqrt{2}$	$-\sqrt{2}$	$-\sqrt{2}$
Case II	488.02	$+\sqrt{2}$	$-\sqrt{2}$	$-\sqrt{2}$	$-\sqrt{2}$
Case III	509.66	$-\sqrt{2}$	$-\sqrt{2}$	$-\sqrt{2}$	$+\sqrt{2}$

If Stock A has an alternate disposal value of 357.00, then it should never be cracked under the price structure conditions represented by Cases II or III, and when it is cracked, factor x_4 is the only variable affected by the going prices, it being decreased as the price differential rises. With an alternate disposal value of 310.00, Stock B should always be cracked, but here factor x_3 is the only variable held constant under changing price structure conditions.

This paper has attempted to show how design of experiments, correlation, and response surface exploration may be utilized in paper studies of going plant operations to reduce costs of experimentation and assure proper operating conditions to attain maximum profit under any set of economic values with alternate methods of disposal for any given product.

APPLICATIONS OF FACTORIAL χ^2 ANALYSIS TO EXPERIMENTS IN CHEMISTRY

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In many research situations, the nature of the experimental materials and phenomena dealt with render the expression of observations in terms directly amenable to analysis by commonly utilized statistical methods, time-consuming and perhaps unduly difficult. This is particularly true in those instances where the experimental observations are of the 'all-or-nothing' type, i.e., where an individual observation can not be expressed in quantitative terms but only can be placed in one of two outcome categories. For the sake of convenience, the terms success and failure will be used throughout this presentation to designate these outcomes.

Such data, commonly referred to as attribute or enumeration data, frequently are recorded as ratios, proportions or percentages and to subject them to analysis of variance, for example, it is customary to transform the original data to other 'normalized' values such as angles or probits. These, and similar methods, often permit extensive and profitable treatment of attribute data, but they are time-consuming and do require considerable familiarity with statistical methods. Unfortunately, many experimenters have an exaggerated concept of the difficulties involved and, as a consequence, these methods have not received the use they truly deserve.

Data of the 'all-or-nothing' type can be subjected to χ^2 analysis directly through the use of simple techniques readily available in practically all statistical texts. However, when the experimental design is at all complex or many treatment groups are used, the resultant total χ^2 based on multiple degrees of freedom often is of little real value as an aid to understanding or interpreting the results. The investigator wants to know what was significant,- which factor or factors were responsible. Also, he frequently desires concomitant detection and assessment of the effects of multiple factors and their interdependence (interactions).

Experiments which permit concomitant assessment of the effects of multiple factors (or levels) and their interactions commonly are known as factorial experiments and procedures appropriate for their statistical analysis are readily available. These procedures require that the data (usually measurements) are normally distributed. Thus, if they are used with attribute data, some 'normalizing' transformation should be employed. Too little attention has been paid to analysis of experiments involving attribute data without transformation. In notable exception to this, Dr. A. E. Brandt (currently, Biometrician, Atomic Energy Commission) has developed a computational procedure which greatly facilitates χ^2 analysis of attribute data from certain factorial experiments.

The method, termed "Factorial Chi-square" by Brandt (1), has not been published except in abstract form (2) and is known to this writer and others only through personal association with Dr. Brandt. The procedure has been found exceedingly useful in analysis of attribute data from a wide variety of sources. It is the purpose of this publication to

make the essential features of the method more widely available and to illustrate its use with selected examples from industrial research[1].

THE METHOD

Factorial χ^2 analysis of attribute data, as proposed by Brandt, essentially is analysis of variance with the estimates of variance from binomial data 'normalized' by expressing them in terms of individuals per individual.

The error variance used for testing significance is the population variance (NPQ) calculated from the totals of the outcome groups 'normalized' by dividing by the total individuals (NPQ/N = PQ) and, being a 'population' value, has infinite degrees of freedom. For computational convenience, the 'normalized' error variance (PQ) is not used as a divisor. Rather, its reciprocal (1/PQ) is used as a multiplier and is calculated as $N^2/(SxF)$ directly from the experimental totals where N = total individuals, and S and F (successes and failures) = the totals of the two outcome groups. It makes no difference which outcome is designated as success and which as failure.

For a typical factorial experiment with experimental units of equal size (n) and employing factorial coefficients, the formula for calculation of χ^2 for each degree of freedom (as designated by the subscript in brackets) is:

$$\chi^2_{[1]} = N^2/(SxF) \times T^2/D \qquad \text{(Formula 1)}$$ [2]

where T = the total of the sums of products of the factorial coefficients x the number of successes (or failures) in the corresponding experimental units; D (the divisor) = the product of the sums of squares of the coefficients x n (the number of individuals per group); and the other symbols have the meanings previously defined.

Brandt's formula can be modified to an equivalent, more general form (Formula 2) for calculation of χ^2 with multiple degrees of freedom, such as total χ^2, subclass χ^2, etc. This form also can be applied to single classification, multiple group data where the experimental groups are not of equal size.

$$\chi^2_{[k-1]} = N^2/(SxF) \times SS \qquad \text{(Formula 2)}$$

where N, S, and F and the subscript in brackets have the same meanings as before; k = the number of groups involved; and, SS = the 'between groups' sum of squares. SS is calculated from 1, 2, --- k groups of n_1, n_2, --- n_k individuals as follows:

$$SS = (T_1^2/n_1 + T_2^2/n_2 + \text{---} T_k^2/n_k) - S^2/N$$

where T_1, T_2, etc., and the numerator of the correction term, are the total successes (or failures) in the respective groups.

This method for calculating χ^2 (Formula 2) is not new and has been referred to as the "Brandt-Snedecor" method. It has appeared, although with different symbolism, in various publications such as (3, 4, 5, 6).

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1. All data presented were obtained from the Continental Can Co., Chicago, through the courtesy of Miss Mae-Goodwin Tarver, Statistician, Research Division.

2. Credit for development of this formula should revert exclusively to Dr. Brandt who generously has approved and encouraged this publication.

EXAMPLES

1. Analysis of a 2 x 2 factorial experiment.

Factorial χ^2 analysis of a 2 x 2 factorial experiment is illustrated with data obtained in a study of the effect of coating weight and plate type of base steel on the resistance of metal containers to corrosion. Two levels of each factor were employed as follows: coating weight (A_1 = low weight, A_2 = high weight); plate type of base steel (B_1 = low phosphorous content, B_2 = high phosphorous content). A highly corrosive substance was dispensed into containers which then were stored at a high temperature to accelerate corrosion. Results of the experiment are presented in TABLE 1.

By conventional means; i.e., by calculation of expected values in accordance with the null hypothesis and computing χ^2 as $\Sigma[(O-E)^2/E]$, the total χ^2 with 3 degrees of freedom is found to be 15.01. This value is highly significant ($p < 0.01$). This information is of limited direct usefulness, however, as the sources of the significance are not identified. It is true that considerable insight as to the major sources can be gained from studying the contributions to χ^2 from the various cells of the table. In many instances, less clear-cut than the foregoing, the nature or magnitude of these contributions is insufficient to insure interpretation with confidence.

TABLE 1
EFFECT OF PLATE TYPE AND COATING WEIGHT ON FAILURE OF METAL CONTAINERS FROM CORROSION
(Failures/containers tested)

Plate type (phosphorous content)	Coating weight		Totals
	Low	High	
Low	12/36	7/37	19/72
High	22/36	18/36	40/72
Totals	34/72	25/72	59/144

Analysis of the same data by Brandt's factorial χ^2 method is shown in TABLE 1A.

TABLE 1A
FACTORIAL χ^2 ANALYSIS OF THE DATA FROM TABLE 1

A Coating weight	A_1		A_2								
B P content	B_1	B_2	B_1	B_2							
Failures/36	12	22	7	18	$\Sigma+$	$\Sigma-$	T	T^2	D	T^2/D	χ^2 *
Main effects											
A	+	+	-	-	34	25	9	81	144	0.56	2.31
B	+	-	+	-	19	40	21	441	144	3.06	12.64
Interaction											
AB	+	-	-	+	30	29	1	1	144	0.01	0.04

*$\chi^2[1] = N^2/(SxF) \times T^2/D = 144^2/(85x59) \times T^2/D = 4.13 \times T^2/D$.

Factor headings and outcome data are arranged in the form shown for computational convenience. The calculations can be performed using either success or failure data. In each example used in this presentation, physical failure actually was the attribute of interest. Therefore all calculations were performed utilizing 'failure' data. The independent comparisons are fixed by the design of the experiment. These are designated by assignment of coefficients, + and - (actually, + 1 and -1), taking care to observe the rules of orthogonality (independence). The order of assignment of coefficients (+, - or -, +) is immaterial for purposes of calculating χ^2. Coefficients for the interaction are obtained by cross multiplying, column by column, the coefficients for the factors involved.

The quantities entered in the columns headed $\Sigma+$ and $\Sigma-$ are obtained by summing the products of the coefficients and the number of failures in the corresponding experimental groups. Thus, for the first comparison A, the quantity $\Sigma+$ is obtained as $(+1x12) + (+1x22) = 34$, and $\Sigma-$ is computed as $(-1x7) + (-1x18) = -25$. The value entered in the column headed T is obtained as the sum of these quantities, $(+34) + (-25)$, or + 9. T may be either positive or negative but need not be recorded as such as it is squared in the next operation and entered in the column headed T^2.

D, the divisor, is obtained for each row as the sum of the squares of the coefficients x the number of indiviiduals per experimental unit (n). Again for comparison A; $D = [(+1)^2 + (+1)^2 + (-1)^2 + (-1)^2] \times 36 = 144$. In this problem the value of D is the same for each comparison (row). In many instances such is not the case.

The value entered in the column headed T^2/D is obtained by performing the indicated division. This is the 'normalized' 'between groups' mean square for the comparison.

Values of T^2/D are obtained for each row (comparison) in the foregoing manner and individual values of χ^2 are obtained by multiplying each value of T^2/D by a constant determined as $N^2/(SxF)$. Substituting the appropriate values from this problem; $N^2/(SxF) = 144^2/(85x59) = 4.13$ and the resultant χ^2's are 2.31, 12.64 and 0.04. A summary of the analysis is presented in TABLE 1B.

TABLE 1B
SUMMARY OF FACTORIAL χ^2 ANALYSIS OF THE DATA FROM TABLE 1

Comparisons	DF	χ^2
Main effects		
A Coating weight	1	2.31
B Plate type	1	12.64
Interaction		
AB	1	0.04
Totals	3	14.99

The sum of these 3 values of χ^2, each with 1 degree of freedom, is 14.99, the same as the total χ^2 obtained by the conventional method except for a minor discrepancy resulting from carrying only 2 decimal

places during calculations. In other words, the total χ^2, with 3 degrees of freedom, has been partitioned into 3 individual χ^2's, each with 1 degree of freedom. These individual χ^2's, permit independent assessment of the effects of the two factors (type of base plate and coating weight) and their interdependency (interaction).

The only χ^2 significant at commonly accepted levels was that for type of base plate (low vs high phosphorous content),- $\chi^2 = 12.64$, ($p < 0.001$). Neither the χ^2 for coating weight nor that for interaction was significant. The latter is of special interest since it indicates that the effect of phosphorous content of the base plate on corrosion rate of the containers is independent of coating weight, at least within the range of coating weights studied.

It is obvious that considerably more specific information of direct usefulness to the experimenter was obtained by factorial χ^2 analysis than with the conventional total χ^2 having 3 degrees of freedom. Yet the cost in effort, materials, and time was the same.

2. Analysis of a replicated factorial experiment (2 x 2 x 6).

The role of replication in experimental investigations requires no elaboration here. The computational procedure employed with the preceding example can be extended readily to typical replicated experiments provided, of course, that the design and procedures actually used justify such application. Replication is treated as a main effect and the various interactions between replicates and other factors (or levels of factors) can be calculated in either of two ways; the method of choice being determined by the actual design and conditions of the experiment and the desired form of the final analysis.

If experimental interest is directed towards differences between specific replications, such as in detection of trends, χ^2 values based on single degrees of freedom may be desired. In that case, appropriate coefficients (such as coefficients of the orthogonal polynomials) may be employed and the analysis completed in a manner similar to that previously presented.

If there is no interest in the differences between specific replications, calculation of χ^2 values with multiple degrees of freedom for replications, and for interactions involving replications, can be accomplished more easily by employing Formula 2 previously presented. χ^2 between replicates can be calculated from replicate totals and χ^2 for interactions can be calculated from tables of subclass totals in the manner frequently employed in analysis of variance calculations.

Analysis of a replicated factorial experiment is illustrated with data from another experiment dealing with corrosion of metal containers. Two types of containers; A_1 = not lacquered, A_2 = lacquered; and 2 corrosion inhibitors, B_1 and B_2, were employed. All containers were stored at a high temperature to accelerate corrosion and the experiment was replicated 6 times. Results of the experiments are presented in TABLE 2 (on next page).

Total χ^2 with 23 degrees of freedom calculated by the conventional method is 89.84. This is highly significant ($p < 0.001$) but the sources of significance are not at all apparent by mere inspection of the data.

TABLE 2
EFFECT OF LACQUER AND CORROSION INHIBITORS ON THE FAILURE OF METAL CONTAINERS FROM CORROSION
(Failures/containers tested)

Replication	Not lacquered		Lacquered		Totals
	Inh. B_1	Inh. B_2	Inh. B_1	Inh. B_2	
1	20/36	20/36	19/36	5/36	64/144
2	11/36	15/36	15/36	6/36	47/144
3	21/36	15/36	20/36	15/36	71/144
4	13/36	10/36	22/36	8/36	53/144
5	7/36	18/36	18/36	5/36	48/144
6	5/36	12/36	20/36	9/36	46/144
Totals	77/216	90/216	114/216	48/216	329/864
	167/432		162/432		

Factorial χ^2 analysis of the data is best accomplished in a series of steps employing both the formulas given. A subclass table obtained by summing over replications permits calculations of χ^2's for the main effects of the experimental factors and their interaction in the manner previously employed (TABLE 2A).

TABLE 2A
SUBCLASS TABLE: SUMMING OVER REPLICATIONS

A Container type	A_1		A_2								
B Inhibitor	B_1	B_2	B_1	B_2							
Failures/216	77	90	114	48	$\Sigma+$	$\Sigma-$	T	T^2	D	T^2/D	χ^2 *
Main effects											
A	+	+	-	-	167	162	5	25	864	0.03	0.13
B	+	-	+	-	191	138	53	2,809	864	3.25	13.78
Interaction											
AB	+	-	-	+	125	204	79	6,241	864	7.22	30.61

* $\chi^2[1] = N^2/(SxF) \times T^2/D = 864^2/(535x329) \times T^2/D = 4.24 \times T^2/D$.

χ^2 for replications (R) with 5 degrees of freedom is calculated from the marginal and grand totals of TABLE 2 using Formula 2 as follows:
$\chi^2[5] = [864^2/(535x329)] \times [(64^2 + 47^2 + 71^2 + 53^2 + 48^2 + 46^2)/144 - 329^2/864]$
$= 4.24 \times (128.99 - 125.28) = 15.73.$

Additional subclass tables obtained by summing over each factor in turn permit calculation of χ^2's for interactions of replications with other factors. For example, the replications x type of container interaction (AR) is calculated from a subclass table obtained by summing over inhibitors (TABLE 2B on the following page).

TABLE 2B
SUBCLASS TABLE: SUMMING OVER INHIBITORS
(Failures/total containers)

Replication	Type of container		Totals
	Not lacquered	Lacquered	
1	40/72	24/72	64/144
2	26/72	21/72	47/144
3	36/72	35/72	71/144
4	23/72	30/72	53/144
5	25/72	23/72	48/144
6	17/72	29/72	46/144
Totals	167/432	162/432	329/864

A subclass sum of squares is calculated from the 12 cell totals and the grand total,-

Subclass SS = $(40^2 + 26^2 + \text{---} 29^2)/72 - 329^2/864 = 7.04$,

and the subclass χ^2 is obtained by multiplying this by $N^2/(SxF)$ yielding $4.24 \times 7.04 = 29.85$. Since the χ^2 values for types of containers and for replications have been determined previously, χ^2 for their interaction (AR) can be obtained by subtraction,-

AR interaction $\chi^2 = 29.85 - (0.13 + 15.73) = 13.99$.

The replications x inhibitors interaction (BR) χ^2 is obtained in a similar manner; i.e., by constructing a subclass table by summing over container types, computing the subclass χ^2, and subtracting the χ^2 values for replications and inhibitors. To economize on space, the calculations will not be presented in detail but the BR interaction χ^2 is found to be $34.90 - (13.78 + 15.73) = 5.39$.

Finally, the χ^2 value for the second order or 3 factor interaction (ABR) is obtained by computing the total χ^2 and subtracting each of the χ^2's for main effects and first order (2 factor) interactions. The total χ^2 calculated from the original data (TABLE 2) is $[864^2/(535 \times 329)] \times [(20^2 + 11^2 + \text{---} 9^2)/36 - 329^2/864] = 89.85$, and the second order interaction χ^2 obtained by subtraction is $89.85 - (0.13 + 13.78 + 30.61 + 15.73 + 13.99 + 5.39) = 10.22$. The completed analysis is summarized in TABLE 2C (on the following page).

In interpretations of an analysis of this kind, attention should first be directed to the interactions. The AR interaction is significant ($p < 0.05$), indicating inconsistency in the effect of factor A (type of container) from replication to replication. This should be taken into consideration in assessing the main effect of A. In this experiment, however, this main effect is trivial so no further attention need be devoted to the AR interaction.

The AB interaction is highly significant ($p < 0.001$), clearly indicating that the relative effectiveness of inhibitors B_1 and B_2 was markedly dependent upon the type of container used,- non-lacquered or lacquered. This interdependency is obvious, of course, upon inspection of the data (TABLE 2).

TABLE 2C
SUMMARY OF FACTORIAL χ^2 ANALYSIS OF DATA FROM TABLE 2

Comparisons	DF	χ^2
Main effects		
A Type of container	1	0.13
B Inhibitors	1	13.78
R Replications	5	15.73
Interactions		
AB	1	30.61
AR	5	13.99
BR	5	5.39
ABR	5	10.22
Totals	23	89.85

Since the AB interaction is highly significant, the apparently significant χ^2 for factor B (inhibitors) is essentially meaningless. One certainly could not generalize regarding the relative effectiveness of the inhibitors. It is possible, of course, to compare their effectiveness first when used with one type of container and then with the other, and to obtain χ^2 values, each with 1 degree of freedom, for the two comparisons. Either of two general procedures are easily followed. One method maintains the exact additivity of the total χ^2 but is somewhat the less reliable; the other does not maintain exact additivity but is considered preferrable in certain cases. These procedures (and others of a similar nature) have been dealt with extensively by Cochran (3) so attention here will be limited primarily to the computational procedures.

In the additive case, χ^2 values, each with 1 degree of freedom, are calculated for 'between inhibitors' for each container type, A_1 and A_2, using Formula 1. The 'population' error term $[N^2/(SxF)]$ is used and, since only two comparison groups of equal size are involved, the quantity T^2/D is calculated as the square of the difference in failures in the groups, divided by 2n. Thus, for the comparison, B_1 vs B_2; containers type A_1:

$$\chi^2_{[1]} = 4.24 \times (77-90)^2/432 = 1.65.$$

For the comparison, B_1 vs B_2; containers type A_2:

$$\chi^2_{[1]} = 4.24 \times (114-48)^2/432 = 42.74.$$

It should be noted that the sum of these χ^2's is 44.39; identical with the sum of the χ^2s for main effect B and the AB interaction obtained previously (13.78+ 30.61 = 44.39).

Calculation of the non-additive χ^2's requires a little more effort as new error terms must be computed for each comparison separately using for values of N, S and F, subtotals obtained from only those portions of the data concerned. Otherwise the procedure is the same as the foregoing. For the comparison, B_1 vs B_2; containers type A_1:

$$\chi^2_{[1]} = 432^2/(265x167) \times (77-90)^2/432 = 1.65.$$

For the comparison, B_1 vs B_2; containers type A_2:

$$\chi^2_{[1]} = 432^2/(270x162) \times (114-48)^2/432 = 43.04.$$

The sum of these χ^2's is 44.69 and the exact additivity has not been

maintained.

Results of the complete modified analyses are summarized and presented in condensed form in TABLE 2D. To save space and permit direct comparison, the additive and non-additive analyses are presented together.

TABLE 2D
SUMMARIES OF MODIFIED FACTORIAL χ^2 ANALYSES OF THE DATA FROM TABLE 2

Comparisons	DF	χ^2	
		Additive	Non-additive
Main effects			
A Type of container	1	0.13	0.13
B Inhibitors			
In containers A_1	1	1.65	1.65
In containers A_2	1	42.74	43.04
R Replications	5	15.73	15.73
Interactions	15	29.60	29.60
Totals	23	89.85	90.15

Interpretation of the analysis summarized in TABLE 2D is essentially the same as before. The highly significant difference between inhibitors in lacquered containers, and the absence of any significant difference in non-lacquered containers, represents the same interdependency of factors as the AB interaction in the previous analysis. The modified form does point out the specific source of discrepancy, while the interaction term does not indicate whether the major difference in the effectiveness of the inhibitors was experienced with lacquered or non-lacquered containers. That, of course, can be determined just by looking at the data.

In some instances the modified form of analysis may be the much more informative. For example, assume that one of the two inhibitors had been significantly superior to the other in both types of containers but to markedly different degrees. In such a case, the inhibitors-containers interaction well might be significant and possibly lead to a false interpretation.

The difference between the additive and non-additive χ^2's obtained in the modified analyses of these data was trivial. However, such is not always the case. The additive and non-additive χ^2's usually are nearly identical when the main effect of the interacting factor (type of container in this case) is small. When this main effect is large, the alternate χ^2's may differ markedly,- even leading to different conclusions.

The general analytical procedures presented can be extended considerably further if such extension is indicated by the particular situation. For example, the preceding analysis could be extended to include 'breaking down' the 20 degrees of freedom for replication and interactions involving replications in a different manner such as 'replications within types of containers' and 'replications x inhibitors interactions within types of containers', etc. If these interaction χ^2's proved significant, the 'between inhibitors within types of containers' significance tests

TABLE 3A
FACTORIAL χ^2 ANALYSIS OF DATA FROM TABLE 3

A Size	A_1						A_2											
B Temperature	B_1			B_2			B_1			B_2								
C Copper	C_1	C_2	C_3	C_1	C_2	C_3	C_1	C_2	C_3	C_1	C_2	C_3						
Failures/20	2	10	12	6	15	18	2	2	6	4	9	11	$\Sigma+$	$\Sigma-$	T	T^2	D	T^2/D	χ^2 *
Main effects																			
A	+	+	+	+	+	+	-	-	-	-	-	-	63	34	29	841	240	3.50	14.52
B	+	+	+	-	-	-	+	+	+	-	-	-	34	63	29	841	240	3.50	14.52
C_L	-	0	+	-	0	+	-	0	+	-	0	+	47	14	33	1089	160	6.81	28.26
C_Q	+	-2	+	+	-2	+	+	-2	+	+	-2	+	61	72	11	121	480	0.25	1.04
Interactions																			
AB	+	+	+	-	-	-	-	-	-	+	+	+	48	49	1	1	240	---	---
AC_L	-	0	+	-	0	+	+	0	-	+	0	-	36	25	11	121	160	0.76	3.15
AC_Q	+	-2	+	+	-2	+	-	+2	-	-	+2	-	60	73	13	169	480	0.35	1.45
BC_L	-	0	+	+	0	-	-	0	+	+	0	-	28	33	5	25	160	0.16	0.66
BC_Q	+	-2	+	-	+2	-	+	-2	+	-	+2	-	70	63	7	49	480	0.10	0.42
ABC_L	-	0	+	+	0	-	+	0	-	-	0	+	31	30	1	1	160	0.01	0.04
ABC_Q	+	-2	+	-	+2	-	-	+2	-	+	-2	+	63	70	7	49	480	0.10	0.42

* $\chi^2_{[1]} = N^2/(SxF) \times T^2/D = 240^2/(143x97) \times T^2/D = 4.15 \times T^2/D$.

used in the modified analysis would be suspect. The χ^2's can be changed to mean squares, and variance ratios used as tests of significance. Space does not permit further elaboration here and the interested reader is referred to Cochran (3) for an excellent introduction to such techniques.

3. Analysis of a 2 x 2 x 3 factorial experiment using coefficients of the orthogonal polynomials.

In certain experiments where one or more factors are employed at several levels differing by a constant increment, and the number of observations per group is constant, it is possible to partition multiple degrees of freedom 'between levels' into individual degrees of freedom associated with the independent regression components,- linear, quadratic, cubic, etc. The procedure is illustrated with data from another study of the effects of various factors on the corrosion of metal containers.

In this experiment, copper (a corrosion accelerator) was added at 3 levels (C_1 = 5, C_2 = 10 and C_3 = 15 ppm) to containers of 2 sizes (A_1 = small, A_2 = large) which then were stored at 2 temperatures (B_1 = 75°F, B_2 = 98°F). Results of the experiment are presented in TABLE 3.

TABLE 3
EFFECT OF CONTAINER SIZE, STORAGE TEMPERATURE AND LEVEL OF ADDED COPPER ON FAILURE OF METAL CONTAINERS DUE TO CORROSION
(Failures/containers tested)

Level of copper (ppm)	Small		Large		Totals
	75°	98°	75°	98°	
5	2/20	6/20	2/20	4/20	14/80
10	10/20	15/20	2/20	9/20	36/80
15	12/20	18/20	6/20	11/20	47/80
Totals	24/60	39/60	10/60	24/60	97/240

For analysis of these data by factorial χ^2 they are arranged as shown in TABLE 3A (on the preceding page). Coefficients for the comparisons representing the main effects of container size and storage temperature are obvious by inspection. Coefficients for the linear and quadratic components of 'levels of copper' are obtained from any table of coefficients of the orthogonal polynomials, such as Fisher and Yates (7). The identity of the 7 interactions is uniquely set by the design of the experiment and their coefficients are obtained by cross multiplying, row by row, the coefficients of the main effects or interactions involved. It will be noted that the coefficients are not all unity in this example and, thus, the divisors in the column headed D are not constant. Completion of the analysis is performed in a manner comparable to that employed with the previous examples and will not be discussed in detail.

Upon completion of the analysis, it is seen that 3 main effects, container size, storage temperature, and the linear component of level of copper added, are highly significant. The χ^2 value for the first order interaction AC_L (container size x linear component of level of copper) is sufficiently large to attract attention ($p < 0.10$). Since none of the

other comparisons approaches significance, the analysis can be summarized as shown in TABLE 3B for purposes of presentation or reference.

TABLE 3B
SUMMARY OF FACTORIAL χ^2 ANALYSIS OF DATA FROM TABLE 3

Comparison	DF	χ^2
Main effects		
A Container size	1	14.52
B Storage temperature	1	14.52
C Level of copper		
C_L Linear component	1	28.26
C_Q Quadratic component	1	1.04
Interactions		
AC_L	1	3.15
All others	6	2.99
Totals	11	64.48

The significant effect of container size indicates that surface/volume ratio is an important factor in corrosion studies. The significant effect of storage temperature was in accordance with expectation,- relatively high storage temperatures are used deliberately to accelerate corrosion in studies of this type.

Dealing with the combined data (summing over both container sizes and storage temperatures), a highly significant linear relationship between corrosion rate and copper content was found (comparisons C_L = slope and C_Q = departure from linearity). The AC_L interaction, while not significant by commonly accepted standards, suggests that the slopes of the corrosion-copper regression lines for small and large containers may truly be different. Thus, one should hesitate to predict corrosion failures at a given level of copper without taking container size into consideration.

COMMENTS

The computational procedure for factorial χ^2 analysis developed by Brandt and presented here as Formula 1, previously has not been published in detail. This is considered unfortunate as it has been found useful by this writer and certain colleagues in the analysis and interpretation of data from a considerable number and variety of experiments. The general procedure followed in factorial χ^2 analysis using Formula 2 has appeared previously and has been referred to as the Brandt-Snedecor method. Only 3 examples of applications of these techniques have been presented here,- many more are available.

A primary advantage of these methods is the ease and speed with which certain complex problems can be analyzed employing only techniques readily mastered by those having a moderate training in statistical method.

Procedures for the partition of χ^2 with multiple degrees of freedom

into individual χ^2's with single degrees of freedom (with or without loss of additivity) are not new. As mentioned previously, Cochran (3) has dealt fairly extensively with such situations. Lancaster (8, 9) and Irwin (10) have dealt with several mathematical approaches to the exact and non-exact partition of χ^2 into single degree of freedom χ^2's from 'r x s' (row by column) contingency tables. More recently Kimball (11) has published certain "short-cut formulas" for the exact partition of χ^2 as an extension of the Lancaster-Irwin procedures. It is interesting to note in this regard that when the illustrative data presented by Kimball are analyzed by factorial χ^2 (Formula 2), the results are identical and less actual computational effort is required. If the data presented had been based on groups of equal size, Formula 1 could have been used with an even further reduction in effort. Unfortunately, this identity apparently holds only for the 2 x s case.

When dealing with the results of actual experiments, the isolation and assessment of specific interactions often is of great practical interest and value. Such generally is not feasible employing conventional χ^2 analysis techniques. Isolation and assessment of interactions from data of the type considered here can be accomplished in other ways. The method proposed by Gore (12) is considerably more laborious; the relative statistical efficiency of the two methods has not been studied. The procedure presented by Bartlett (13) no doubt has greater efficiency, but is readily applicable to data involving only a limited number of factors or levels. Suggestions made by Cochran (3) concerning assessment of main effects in the presence of interactions, presumably could be extended to assessment of the interactions themselves. However, he proposed no specific procedure.

The general factorial χ^2 procedure has been attacked by mathematicians,- no doubt justifiably. Individual tests of significance do lose sensitivity and reliability in the presence of strong main effects, marked interactions, or when unduly large and small proportions are involved within the same body of data. The assumption of homogeneous variance (innate to the use of the common error term PQ throughout) obviously is not valid in such cases. If there is marked variation in the proportions encountered in certain comparisons, the error term is biased upwards and the level of significance is underestimated. In many instances these objections may be of greater academic interest than practical importance, and it is questioned whether such limitations are peculiar solely to the procedures referred to as factorial χ^2 analysis. Further study of many (if not all) proposed procedures might well prove profitable.

If situations of the type discussed in the preceding paragraph are encountered when dealing with a problem requiring significance tests of high reliability and efficiency, other more formal procedures no doubt should be considered. If, however, the data are not too heterogeneous (proportions ranging say from about 0.15 to 0.85), experimental groups are of reasonable size (15, 20 or larger), not too many strong main effects or interactions are encountered, and, of great importance, if the primary interest of the experimenter is in identifying the existence or sources of variation rather than in estimating significance levels with minimal uncertainty, the factorial χ^2 procedures can be very useful. In many instances this writer has analyzed attribute data from complex factorial experiments by both the factorial χ^2 method and by formal methods using transformations such as probits, angles, etc. While the probability

levels of the resultant χ^2's and variance ratios have differed (sometimes appreciably), in no instance have the alternate methods led to different interpretations,- this may have been at least partly fortuitous.

Significance tests obtained through factorial χ^2 analysis are approximations but, except for extreme cases, they appear to be good approximations. As such, they may well be of greater interest (and usefulness too, it is hoped) to experimenters than to statisticians.

SUMMARY

The essential computational details of factorial χ^2 analysis of attribute data, as developed by Brandt, are presented. Certain applications of these methods to data from industrial research are illustrated by examples including a 2 x 2 factorial, a 2 x 2 factorial with 6-fold replication, and a 2 x 2 x 3 factorial experiment involving use of coefficients of the orthogonal polynomials.

Some advantages and limitations of the method are discussed.

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SEARCHING FOR CAUSES IN INTEGRATED METAL INDUSTRIES
-- AN INTRODUCTION --

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A great many people spend an important part of their lives "searching for causes." This begins quite early in life, and as children we ask "Why, Mommy?" until poor Mommy is nearly frantic. The inquisitiveness is seemingly never satiated, and in thousands of ways our desire to know "why" is evidenced throughout our growing years. What makes baby cry, why did the cake fall this time, why are wives so utterly devoid of understanding, and why doesn't my mother-in-law mind her own business are classics. Some individuals finally decide it is not worth the effort and give up. Perhaps they have learned everything important. But others never cease wanting to know what causes a certain situation to exist, what complexities control a given chain of events, what can be done to improve some condition. The true scientist is perhaps peculiar in many ways, not the least of which is his never-ending thirst and search for causes.

Modern competitive industry is largely dependent upon finding out how to make more of a product, make it better, and make it cheaper. A great many people in industry are charged with specific activities in this direction; many owe their entire livelihoods to their ability to search out causes and control them. It is highly obvious that any tool, technique, philosophy or approach which will aid us in detecting and controlling causes is of vital interest. Statistical Quality Control has become well-known as such an aid.

During the early periods of indoctrination into the mysteries of Quality Control the neophyte is usually quite impressed with the somewhat fantastic solutions to apparently hopelessly complex problems which are developed by the instructor. However, being a little short on imagination at this stage of the game he simply cannot see how controlling the diameters of one inch round steel pins can be of much help to him in baking cookies or improving the flavor of whisky. He is quite willing to agree that the technique which has just been demonstrated on the blackboard is "a fine and valuable tool for the inspector of machine-produced parts," but usually hastens to add that "it will not work in my business; my business is different."

The ability to transpose the classroom or lecture problem into a set of conditions with which we are familiar, to apply the technique to a problem which exists in our own industrial environment, is a continuing challenge. Some industries have long been subject to searching analysis by Quality Control enthusiasts, expert and otherwise, and a considerable amount of knowledge has been developed. Others have received barely a casual look. To most people working in the basic metals producing industries, the processes appear to be radically more complex than those of most other industries. This probably has some foundation in fact, but is probably also largely psychological in nature. The fact remains that the useful and profitable application of the techniques of Statistical Quality Control is a difficult and challenging problem in these particular industries, just as it has proven to be in most others.

Searching for causes, trouble shooting, process analysis; call it what you will. How to usefully employ in the metals producing field the techniques which have proven so effective and valuable to others in a large variety of industries? This is the problem. Each individual who has had some practical experience doing just that has naturally developed some favored approaches. Each has his pet tools, his cherished techniques. It is always profitable to examine the success stories of the other fellow.

The following four papers are presented here in the hope that they will be helpful to those who still want to know "why". Stress should be laid on the fact that technique application, although vital, is only the first step. Once the answer to the "why" is obtained, the really successful conclusion to the venture is getting something done about it. Of equal importance to knowing the technique and its efficient application is organizing for corrective action. Otherwise, the entire affair is apt to take on the complexion of an academic exercise for the student. To the "why" must now be added "how".

The techniques employed need not be those of an advanced and highly technical nature. Simple control charts and the lowly frequency distribution have tremendously wide application and are simple to use and to understand. Frequently, however, the situation under study is of such a complex nature that its analysis is dependent upon specifically developed techniques. Some of these are discussed in the accompanying papers along with examples of their application. They have been found to be of proven value to other investigators and it is hoped the reader will find them equally useful. They are but a few of the many techniques finding an ever increasing usefulness in helping to find the answer to the multitude of still unsolved problems in the field of metals.

A NEW METHOD FOR EVALUATING CAUSE

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In working toward the analysis and solution of industrial problems, such as are constantly presented to those in quality control and related fields, one of our most common pitfalls is the tendency to lose sight of the problem originally presented. Thus, the statistician tends to report his findings in terms of variability and probability indices, the industrial engineer in terms of procedures and rate assignments, the operations researcher in terms of operational theory and optimization, and similarly each technical or accounting specialist in the technical terms of his or her particular specialized techniques. These answers may, of course, be closely related to the questions asked, or perhaps may be translatable into precisely what has been asked for. As a rule, however, executive questions are simply phrased in such commonplace terms as Why?, When?, How?, or How much?---and our recommendations stand a much better chance of being acted upon favorably if they can be phrased in the same understandable manner.

A large proportion of the quality control problems arising at our own plant are expressed in terms of cause and effect relationships. Probably a goodly proportion of real problems in general are expressed as "what causes so-and-so?" or "does this cause so-and-so?", or the corollary "will doing this improve that?" The most appropriate answer for a quality control engineer to give to such a question should, obviously, be couched in some mathematical evaluation term for Cause.

There are certain mathematical parameters available at the present time for expressing Cause where cause and effect relationships may reasonably exist. Best-known of these evaluation terms for answering such questions as "what causes Y?" or "does Xi cause Y?" is probably in conjunction with correlation and regression analysis where the correlation coefficient squared (1)

$$r^2 = 1 - \frac{\sigma_{y_x}^2}{\sigma_y^2}$$

is often used as a direct measure of cause. For purposes which will be clear in a moment, let us employ the symbol C for Cause, so that

$$C = r^2$$

and 100C will be equivalent to <u>percent of cause.</u> In multiple correlation, then,

$$C = R^2$$

Another mathematical expression for Cause has been brought out by Day, Del Priore, and Sax (2). Using an analysis of variance approach to regression analysis, they arrive at the expression

$$\frac{SS\ (expl)}{SS\ (total)} = \text{"efficiency"}$$

which is also equivalent to r^2, but uses only sums of squares, as in variance analysis, to measure the efficiency of a regression line.

It is apparent, then, that variance ratios may be used as a mathematical measure of Cause. In statistical terminology, the ratio of explained variance to the total observed variance of a dependent variable is also the most probable value for the cause influence of independent variables on the dependent variable.

At this point, several words of caution are called for regarding the use of some proper philosophical restraint in using the term "cause". As pointed out in some detail by Croxton and Cowden (1), unless a true cause-and-effect relationship exists, it is unsafe to assume that any factor is either cause or effect. A large coefficient of correlation between automobile accident rates and average income tax payments does not imply that automobile accidents shock individuals into making larger income tax payments, nor that paying a large income tax renders one incapable of driving safely. But even where clear cause-effect relationships exist (e.g. in the case of percent defective product, which is typically an effect), actual labelling of some factor as a cause of calculated magnitude is limited in its accuracy by:

a. Significance of the calculated % Cause---for example, we can only say that of the variables encountered during the period this experimental data covers, variable A accounts for 36% of the observed variability of B, with the probability that such an indication of cause could occur due to chance alone only 0.5% of the time.

b. Maintenance of a state of statistical control by all cause and effect factors. This is analogous to Shewhart's Criterion I (4).

The "new method" for evaluating Cause described herein is actually only an extension of the methods discussed above, so that a mathematical evaluation of Cause will be possible in cases where no regression line can be drawn, such as data compilations where several discrete X's, or conditions, are listed with varying observations of Y. Here, tests of significance such as Student's t may be ruled out. Chi-square tests or analysis of variance may be employed to process such data, but raw data such as is usually received on plant operations can be difficult to process by these methods, and results are, of course, in terms of probability that no effect exists (null hypothesis) rather than quantitative % Cause.

THE GEOMETRIC MEAN-VARIANCE RATIO

With the foregoing in mind, we may proceed to a statement of this equation for estimating Cause from operational data on fluctuations in Y at n different levels of X (conditions 1, 2, 3, ..., n):

$$C = 1 - \frac{\sqrt[n]{(\sigma_1')^2 (\sigma_2')^2 (\sigma_3')^2 \cdots (\sigma_n')^2}}{(\sigma_t')^2}$$

or, to determine percent of cause directly:

$$\%C = 100 \left(1 - \frac{\sqrt[n]{(\sigma_1')^2 (\sigma_2')^2 (\sigma_3')^2 \cdots (\sigma_n')^2}}{(\sigma_t')^2} \right)$$

It can be seen that a structural similarity exists between this equation and the r^2 or R^2 type of equation for Cause. Actually, C would be almost identical with r^2 as obtained by ordinary correlation methods in any case where the original data lists at least 3 to 5 Y's for each value of X listed. It may be relevant to mention here, also, the L (likelihood) test (1), Bartlett's test (3), and Cochran's μ tests,

which also employ a geometric mean variance, but in tests for uniformity of data rather than any measure relating to cause.

Our experience thus far with this "Cause Ratio" method, as we have come to designate C in practice, indicates that it may actually be more sensitive than analysis of variance procedures as well as chi-square, due to its employment of all observations toward increasing available degrees of freedom. By the same token, it appears to be somewhat less sensitive than correlation analysis.

There are two requirements for effective use of this procedure which have also been proven out by our plant experience:

a. Unbiased estimates of variance are required for each $(\sigma')^2$ to be calculated. We use the following equation, as most suitable for machine calculation:

$$(\sigma_y')^2 = \frac{\Sigma X_y^2}{(N-1)} - \frac{(\Sigma X_y)^2}{N(N-1)}$$

b. Each level of X should have a minimum of between 3 and 5 observations of Y, in order to avoid the chance occurrence of zero variance at any X, which due to the nature of geometric means would automatically give a 100% reading of C. The exact minimum necessary may be calculated using an estimated standard deviation and the number of significant figures in Y values, but we have found that 5 Y's per X will suffice in nearly every case.

A typical example of use of the Cause Ratio will probably serve best to illustrate how this works in answering management questions.

An inevitable by-product of steel plant operation is a tremendous tonnage of slag, the material which carries the impurities removed from raw materials during the refining process. Since the melting point of slag is considerably lower than that of iron or steel, and its density only about one third that of iron, the slag forms a liquid "blanket" over the molten iron while reacting with it. In blast furnace operation, the slag is tapped off periodically in the course of continuous production of iron and more slag, and thus tends to be rather uniform. However, in the "batch" process usually employed in open hearth steel manufacture, most or all of the slag is tapped out together with the steel. Although this spills off as supernatant liquid from the ladle, some steel is always carried off with the slag. While large "buttons" of scrap iron can be reclaimed economically near the Open Hearth pits, it has been a standard practice for some time to carry out a further reclaiming process at Open Hearth slag dumps.

At our plant in Pueblo, this reclaiming operation is done on a contract basis by an outside firm, which is paid on the basis of percentage of iron in carloads of concentrated metallic slag returned to our plant. Hence, the value used for "% Fe" is of primary importance to all concerned, and the method for determining it has been the source of some debate. Despite the separation of carload lots by size ranges determined on the basis of end use, it is an understandably difficult job to obtain a representative sample from a loaded railroad car, and some sampling error must be allowed for in evaluating differences between carload samples.

Management's question is, therefore, "Are the changes in % Fe reported to us due to actual differences in carload lots, or are they due to our method of sampling?" A cause question, to which we ought to give a cause answer.

The data provided were in the form of % Fe determinations on 3 samples each for 56 carloads of concentrated metallic slag in three size ranges, shipped over a 2-month period. For purposes of brevity, only one size range, classified as "Blast Furnace Fines", will be discussed here (see Figure 1).

It will be noted that presentation of the original data in this form makes available directly values of $\bar{X}$ and R which can readily be plotted on a control chart for observation of long-term trends in % Fe and detection of "maverick" readings which represent unusually poor or rich carloads or improper sampling or measurement. As will be shown, control chart values can also be used for a quick but rough evaluation of Cause.

The next step is to tabulate sums of squares, just as in an analysis of variance. However, instead of pooling rows and /or columns, the internal variance of each row (and, optionally, each column) is determined separately, as shown in Figure 2. Thus, with the additional work of calculating two more sets of values horizontally and vertically ("Variance" and "Log" in Figure 2) as compared with analysis of variance procedure, we obtain, according to our calculations, 61 degrees of freedom in our evaluation of carload variability rather than the 30 degrees of freedom obtainable by analysis of variance procedures, and 89 degrees of freedom in comparing sample numbers rather than the 2 degrees of freedom available in analysis of variance.

As a matter of interest, we kept track of the time required to solve this particular problem by analysis of variance and by the "cause ratio" method:

Analysis of Variance solution:	3 hrs., 40 min.
Cause Ratio solution:	4 hrs., 22 min.

In other words, the "cost" of the more powerful test is about 42 minutes, or 19% more time, as compared to analysis of variance.

Proceeding with the data from Figure 2, the "cause ratios" for carload variation and intra-sample variation are calculated by simple arithmetic:

$$C(\text{carloads}) = 1 - \frac{10.743}{31.788} = 0.66204$$

or, 66.2% of observed variation in % Fe determinations is due to actual differences between carload lots.

$$C(\text{samples}) = 1 - \frac{32.141}{31.788} = -0.01110$$

or, essentially, none of the variation is due to difference between first, second, and third samples. The latter conclusion was actually not necessary for this particular problem, since the method of sampling

Figure 1

Percent Fe Determinations on Blast Furnace Fines Samples

Carload No.	X_1	X_2	X_3	$\bar{X}$	R	ΣX_r
1	46.7	58.0	64.2	56.3	17.5	168.9
2	60.3	70.2	52.9	61.1	17.3	183.4
3	55.8	53.2	45.3	51.4	10.5	154.3
4	53.3	64.7	51.6	56.5	13.1	169.6
5	61.2	59.7	50.7	57.2	10.5	171.6
6	51.4	66.2	56.3	57.9	14.8	173.9
7	50.5	50.4	53.3	51.4	2.9	154.2
8	47.9	53.7	53.8	51.8	5.9	155.4
9	58.9	54.1	54.4	55.8	4.8	167.4
10	64.7	58.8	57.7	60.4	7.0	181.2
11	63.1	64.4	60.4	62.6	4.0	187.9
12	56.9	65.9	58.5	60.4	9.0	181.3
13	64.7	57.5	51.8	58.0	12.9	174.0
14	50.1	50.8	51.0	50.6	0.9	151.9
15	65.3	66.1	54.3	62.2	11.8	185.7
16	58.3	65.7	64.2	62.7	7.4	188.2
17	59.0	60.9	62.5	60.8	3.5	182.4
18	54.6	60.3	62.0	59.0	7.4	176.9
19	59.6	55.6	59.0	58.1	4.0	174.2
20	60.6	52.9	62.9	58.8	10.0	176.4
21	62.1	62.9	64.8	63.3	2.7	189.8
22	61.9	62.2	64.2	62.8	2.3	188.3
23	59.9	60.7	64.7	61.8	4.8	185.3
24	62.7	63.2	62.7	62.7	0.5	188.6
25	61.2	66.9	61.2	63.1	5.7	189.3
26	70.2	56.7	53.7	60.2	16.5	180.6
27	58.3	64.0	63.9	62.1	5.7	186.2
28	62.5	63.7	64.6	63.6	2.1	190.8
29	50.3	51.2	61.6	54.4	11.3	163.1
30	63.7	49.2	60.2	57.7	14.5	173.1
31	61.2	64.7	67.7	64.5	6.5	193.6
ΣX_c	1816.9	1854.5	1816.1			5487.5

Figure 2

Calculation of Variances for Determining Cause Ratio

Carload No.	X_1^2	X_2^2	X_3^2	X_r^2	$(\Sigma X_r)^2$	Variance	Log
1	2180.89	3364.00	4121.64	9666.53	28527.21	78.730	1.896140
2	3636.09	4928.04	2798.41	11362.54	33635.56	75.343	1.877045
3	3113.64	2830.24	2052.09	7995.97	23808.49	29.903	1.475719
4	2840.89	4186.09	2662.56	9689.54	28764.16	50.743	1.705379
5	3745.44	3564.09	2570.49	9880.02	29446.56	32.250	1.508530
6	2641.96	4382.44	3169.69	10194.09	30241.21	56.843	1.754679
7	2550.25	2540.16	2840.89	7931.30	23777.64	2.710	0.432969
8	2294.41	2883.69	2894.44	8072.54	24149.16	11.410	1.057286
9	3469.21	2926.81	2959.36	9355.38	28022.76	7.230	0.859138
10	4186.09	3457.44	3329.29	10972.82	32833.44	14.170	1.151370
11	3981.61	4147.36	3648.16	11777.13	35306.41	4.163	0.619406
12	3237.61	4342.81	3422.25	11002.67	32869.69	23.053	1.362734
13	4186.09	3306.25	2683.24	10175.58	30276.00	41.790	1.621072
14	2510.01	2580.64	2601.00	7691.65	23073.61	0.223	0.348305-1
15	4264.09	4369.21	2948.49	11581.79	34684.49	43.480	1.638290
16	3398.89	4316.49	4121.64	11837.02	35419.24	15.303	1.184785
17	3481.00	3708.81	3906.25	11096.06	33269.76	3.970	0.598791
18	2981.16	3636.09	3844.00	10461.25	31293.61	15.023	1.176766
19	3552.16	3091.36	3481.00	10124.52	30345.64	4.653	0.667733
20	3672.36	2798.41	3956.41	10427.18	31116.96	27.430	1.438226
21	3856.41	3956.41	4199.04	12011.86	36024.04	1.923	0.283979
22	3831.61	3868.84	4121.64	11822.09	35456.89	1.563	0.193959
23	3588.01	3684.49	4186.09	11458.59	34336.09	6.613	0.820399
24	3931.29	3994.24	3931.29	11856.82	35569.96	0.083	0.919078-2
25	3745.44	4475.61	3745.44	11966.49	35834.49	10.830	1.034628
26	4928.04	3214.89	2883.69	11026.62	32616.36	77.250	1.887898
27	3398.89	4096.00	4083.21	11578.10	34670.44	10.643	1.027078
28	3906.25	4057.69	4173.16	12137.10	36404.64	1.110	0.045323
29	2530.09	2621.44	3794.56	8946.09	26601.61	39.443	1.595974
30	4057.69	2420.64	3624.04	10102.37	29963.61	57.250	1.757775
31	3745.44	4186.09	4583.29	12514.82	37480.96	10.583	1.024623

ΣX_c^2	107443.01	111936.77	107336.75	(326716.53)
$(\Sigma X_c)^2$	3301125.61	3439170.25	3298219.21	
Variance	31.837	33.193	31.420	
Log	1.502932	1.521046	1.497206	

Overall Variance $(\sigma_t')^2 = \frac{\Sigma X^2}{(N-1)} - \frac{(\Sigma X)^2}{N(N-1)} = \frac{326\,716.53}{92} - \frac{(5467.5)^2}{93(92)} = 31.788$

Rows, Geometric Mean Variance $(\sigma_r')^2 = Antilog \frac{31.965077}{31} = 10.743$

Columns, Geometric Mean Variance $(\sigma_c')^2 = Antilog \frac{4.521164}{3} = 32.141$

was supposed to be the same for all samples, but it is included here for illustrative purposes. It shows, first, that analysis of data by rows and columns is essentially done the same. Secondly, it shows how this method can yield negative results when an answer is not significant, unlike correlation or regression analysis, which always yields real r's.

Testing the significance of results should be possible by methods analogous to those used in correlation studies. In this case, therefore, we determine.

$$r = \sqrt{C} = \sqrt{0.66204} = 0.814$$

which, with 61 degrees of freedom, shows a high level of significance, well beyond the 1% point.

Our answer to management's question as to the cause of differences in reported % Fe is thus a direct one, that significant carload differences do exist and that they account for about two-thirds of the variability in % Fe readings. Since the residual variability, or 33.8% of total variability, is in this case a measure of inherent sampling error, we were able also to evaluate the method of sampling. Using the average of three sample % Fe's was found to give adequate sensitivity for detection of significant changes in Fe content.

USE OF CAUSE RATIO IN OTHER PROCEDURES

In many cases, the data provided with a problem is derived from past plant records and not from results of any formal experimental design. While such data may be very accurate and dependable, breaking it down into various categories for analysis will usually give a very irregular distribution. Analyzing such problems by conventional statistical methods, therefore, will involve regularizing the data either by eliminating observations from all cells larger than the smallest cell or by complicated mathematical compensations for irregularity. Although the above example employs a regular data distribution, we have actually found this method most useful on irregularly-distributed plant data, since the same procedure applies to such problems with little additional effort.

For example, in our Rail Mill, it was desired to know whether rolling procedures or ingot heating procedures were causing an increased incidence of mechanical rail defects. Data was available by working shifts over the period under study, during which the various rollers had worked between 5 and 11 shifts each, and heaters had worked 2 to 5 shifts each. "Cause Ratio" showed that heaters were definitely more responsible than rollers for mechanical rail defects, exactly the opposite of what had been assumed previously.

When the data provided is regularly distributed, as in the slag processing example used for illustration, somewhat streamlined procedures are possible for obtaining a value for "% Cause". Two of these may be shown by using the same example.

The simplest procedure involves calculation of $(\sigma')^2$ directly from control chart data. (See Figure 3). It is perfectly proper to determine variation due to sampling as

$$\sigma' = \frac{\bar{R}}{d^2} = \frac{7.99}{1.693} = 4.719$$

THE COLORADO FUEL AND IRON CORPORATION - PUEBLO PLANT

QUALITY CONTROL CHART

SUBJECT B.F. FINES (+1/8" -1") FERRO-PROCESSING DEPARTMENT PERIOD COVERED SEPTEMBER-OCTOBER 1955

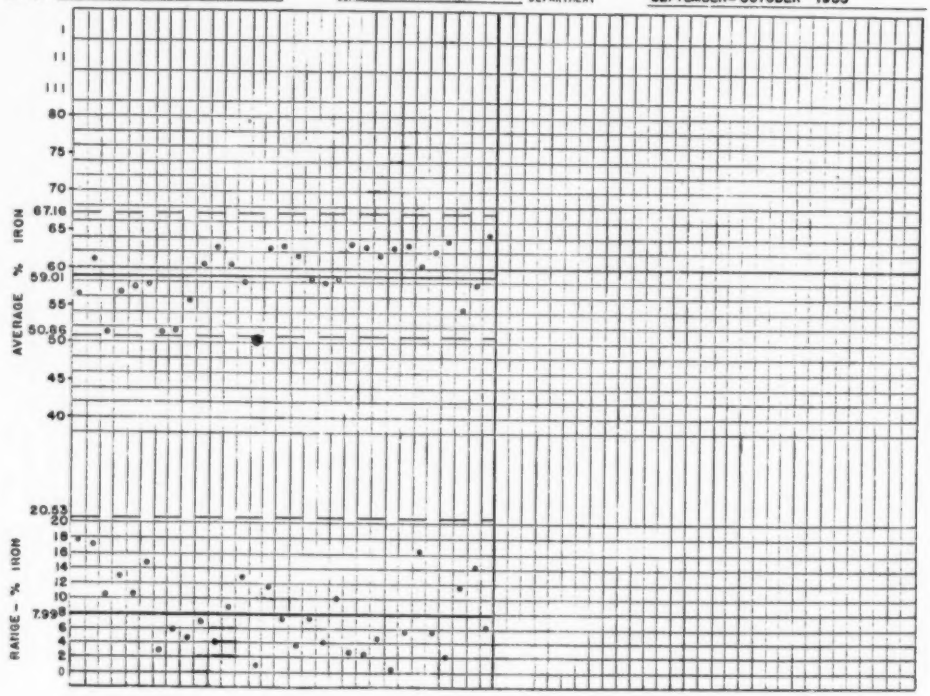

FIG. 3

It would seem that the transition

$$(\sigma')^2 = (\sigma')^2 = 22.269$$

wouldbe even more perfectly proper, but actually this is in the realm of "rough and ready" or "quick and dirty" statistical method, as has been pointed out by the A.S.Q.C. Metals Technical Committee's subcommittee on theoretical statistics (6). However, with the understanding that a short cut is actually being employed, we may use this value with

$$(\sigma_t')^2 = \frac{\Sigma X^2}{(N-1)} - \frac{(\Sigma X)^2}{N(N-1)} = 31.788$$

in the cause equation

$$C \text{ (carloads)} = 1 - \frac{(\sigma')^2}{(\sigma_t')^2} = 0.299$$

and evaluate the contribution of carload differences to overall variation as a significant 29.9%.

Figure 4

ANALYSIS OF VARIANCE

1-Way Table

Source of Variation	Sum of Sqs.	d.f.	Mean Sq.	F Ratio
Rows (carloads)	1414.8940	30	47.16313	1.937 *
Residual (within carloads)	1509.6333	62	24.34892	
Total	2924.5273	92	(31.78834)	

2-Way Table

Columns (samples)	31.0641	2	15.53205	0.630
Rows (carloads)	1414.8940	30	47.16313	1.914*
Residual	1478.5692	60	24.64282	
Total	2924.5273	92	(31.78834)	

Figure 4 shows the summaries of analysis of variance treatment of this same problem, wherein both 1-way and 2-way tables give the answer that carload variability is somewhat significant. In order to extend this to a "% Cause" answer to management's cause question, only the total variance figure (shown in parentheses in Figure 4) need be added to the usual analysis of variance table. Since, in both tables, only between-carloads variance is of significant magnitude, and residual and total mean squares are unbiased estimates of variance, it would appear proper to evaluate explained variance by

$$C \text{ explained} = 1 - \frac{\text{Residual Mean Square}}{\text{Total Mean Square}}$$

This was calculated to be 23.40% in the 1-way table and 22.48% in the 2-way table. Both are significant beyond the 1% probability level.

The discrepancy between "% Cause" calculated by both short-cut methods and that determined by use of the geometric mean-variance ratio

does appear to be somewhat excessive. Whether this is due to some theoretical errors in one or more of the methods described will have to be determined by theoretical statisticians. The fact of greater sensitivity by the longer method has been borne out in every practical application thus far to our plant problems in Pueblo.

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S. Q. C. IN THE GLASS INDUSTRY

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James Doughty
Pittsburgh Plate Glass Company

SUMMARY

This is a description of a developing organization. Its purpose, organization, operation, training, and potentialities are described.

INTRODUCTION

A Statistical Quality Control Department should function to make money and produce management talent. These should be the broad directives and should not be permitted to become obscured because of the inherent difficulty in achieving them within the framework of a staff operation.

Essentially, a Statistical Quality Control Department functions in a staff capacity engaged primarily in communicating. It possess no means of enforcing action beyond that which is inherent in the data it submits, and its usefulness is no greater than the willingness of management to use the knowledge which has been provided.

It is imperative that members of this group recognize their role so that the ways in which they can attain their objectives be fully utilized.

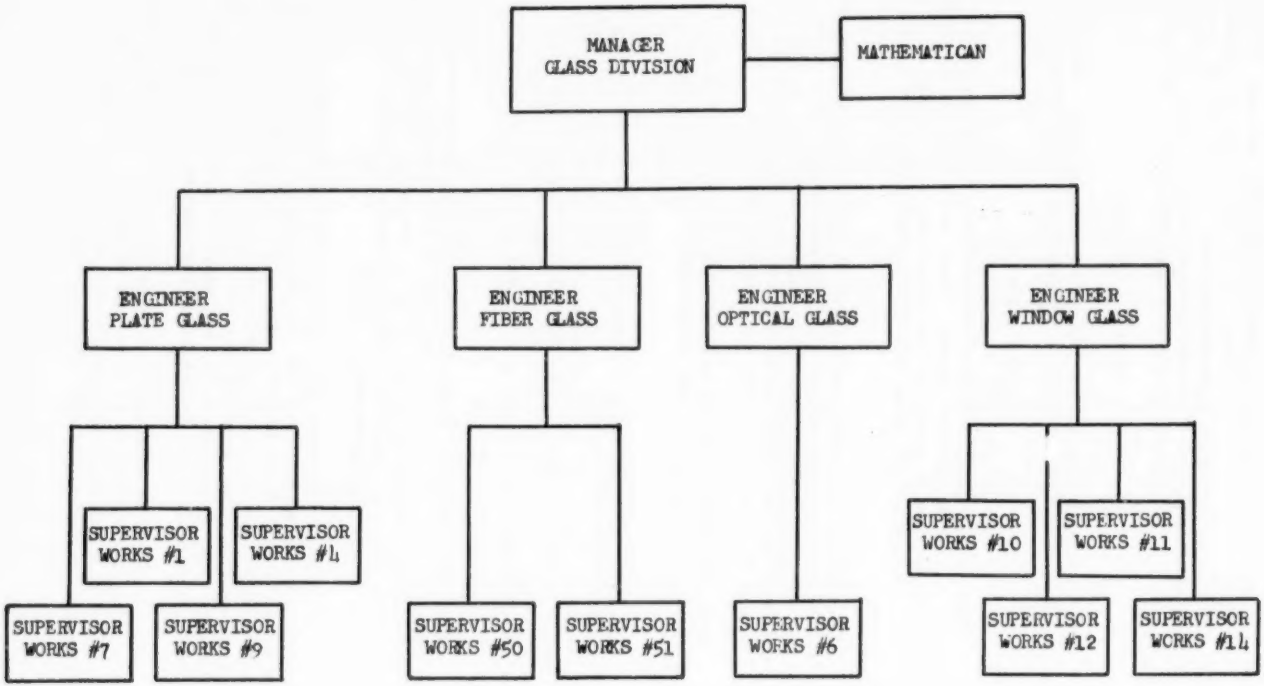
The group must develop its communication networks to carry its information rapidly and clearly. Its communiques must be direct and free of the static which arises from secondary interpretations of its reports. Statistical results must be interpreted in process terminology, product specifications, and dollars and cents. Where specific monetary figures are not desired, data must be so arranged that the inferences are obvious.

After the group has organized its functions in the company, work can be started on the external problems of the company; customer-vendor relationships. Little is to be gained by premature quality certification if the internal Statistical Quality Control measures are not fully installed or are not functioning properly.

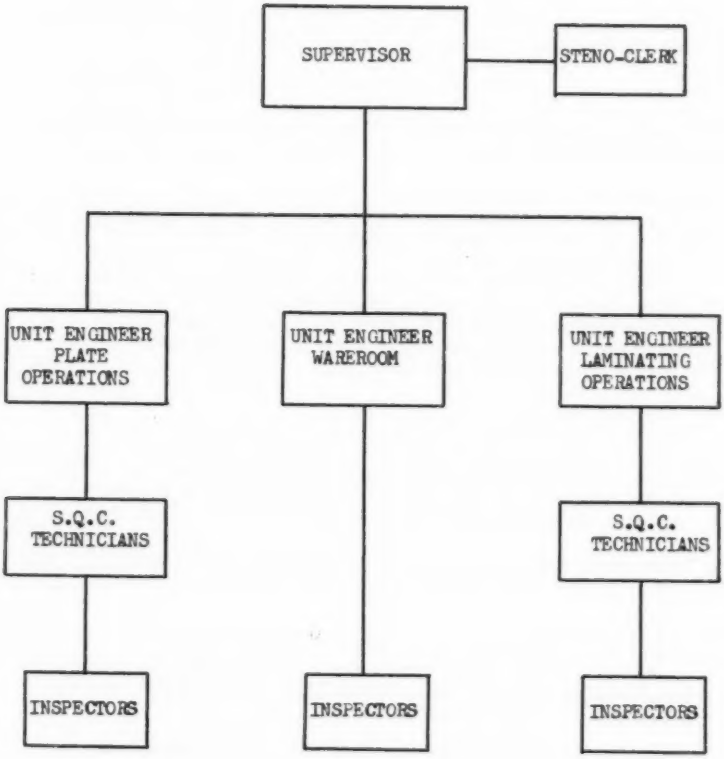
Problems of the scope just outlined cause great emphasis to be placed upon the selection of men for this group. They should have management potential for they learn much from their work in Statistical Quality Control. For example, they learn the difficult art of listening and counseling. They gain insights into company financial and labor problems. They learn processes, and where customer certification exists they learn company sales policies and customer relationships.

This is why we advocate that a member of the Statistical Quality Control group be regarded as potential management talent. He will be an individual who knows his company and his customers and he will have the means for making logical choices in complex situations.

S.Q.C. ORGANIZATION
GLASS DIVISION



S.Q.C. ORGANIZATION
WORKS #1



ORGANIZATION

The charts indicate the structure, not the mode of operation. Area, authority, and responsibility are assigned but the members work as a group. Important problems encountered in any area are discussed during group conferences. Criticisms and suggestions are made at this time. After the discussion is completed, the individual responsible for the area makes his decision and assumes the responsibility for executing the solution.

This gives an individual experience in two skills.

He develops the ability to work as if in a line organization and he develops the ability to work as a member of a group.

OPERATION

The department utilizes various Statistical Quality Control techniques in the different areas.

I. Receiving Inspection Area
Incoming raw materials are tested physically and chemically for conformance to specification. Results are handled on standard quality control charts. Sampling is related to usuage. Sub-groups are determined according to possible effects due to use. e.g. Raw material storage in silos accomplishes a degree of blending. Therefore, incoming shipment samples are sub-grouped according to the number of cars contained in the storage silos.

II. Process Controls
Product and process data are handled by standard control charts. In many cases the nature of the operation is such that deliberate changes are made in various components and at various points in the process. Control charts are therefore plotted as differences from the nominal or desired level.

Where process tolerances are better than specifications, control charts using reject limits are used.

III. Sampling Plans
Product is directed into logical lots and sampling plans are used to control outgoing quality of shipments. To date, work has been done to determine facts prior to discussions with customers on quality certification.

Various sampling techniques have been used although where possible we use multiple sampling plans to permit better use of the inspector's time.

Some aspects of our operations may make it possible to obtain excellent benefits from the techniques of sampling from continuous production.

IV. Special Adaptations of Statistical Techniques

In one particular operation our product changes annually. Many times the change creates entirely new situations and few, if any of the prior years process characteristics can be carried forward.

Under these conditions we use sequential sampling plans in the process to drive the new process to established targets.

This same data is then used to develop knowledge of the process as rapidly as possible so that if a target is not achieved, sufficient information is available to determine whether process changes are necessary.

V. Universal Control Charts

One of the problems in a Statistical Quality Control system is the volume of paperwork. Every effort is made to reduce it. For example, we used standard control charts in which the chart lines are shown in terms of average, one, two and three sigma.

This reduces paperwork and makes quick methods of evaluation possible. Shifts in average are readily detectable in terms of runs of points above or below the average at one, two or three sigma.

These and other activities have created a trained manpower problem for us. To solve it we have moved in two directions; we attempt to hire trained men and we attempt to train inexperienced men. Our training program is a vital part of our work.

TRAINING

Training programs encompass two levels; training at the engineering level; training at the sub-professional level. These are further sub-divided into company training programs and training outside the company.

Engineers in this group are under continuous study programs. Their programs can be outlined as:

I. Programs in Statistical Methods

A. Within The Company
1. discussions and seminars directed by members of the group
2. seminars directed by outside consultants

B. Outside The Company
1. enrollment in special courses at universities
2. attendance at society conferences
3. enrollment in special courses given by qualified consulting staffs.

II. Programs in Other Mathematical Techniques

III. Programs in Management Training

A. Within The Company
   1. conferences on management policies
      a. company policies
      b. labor policies
   2. conferences on management problems

B. Outside The Company
   1. enrollment in special courses at universities
   2. attendance at management society conferences
   3. enrollment in special courses given by qualified consulting staffs.

Technicians are given intensive training in those aspects of their work which are essential to a successful Statistical Quality Control operation.

I. Statistical Training

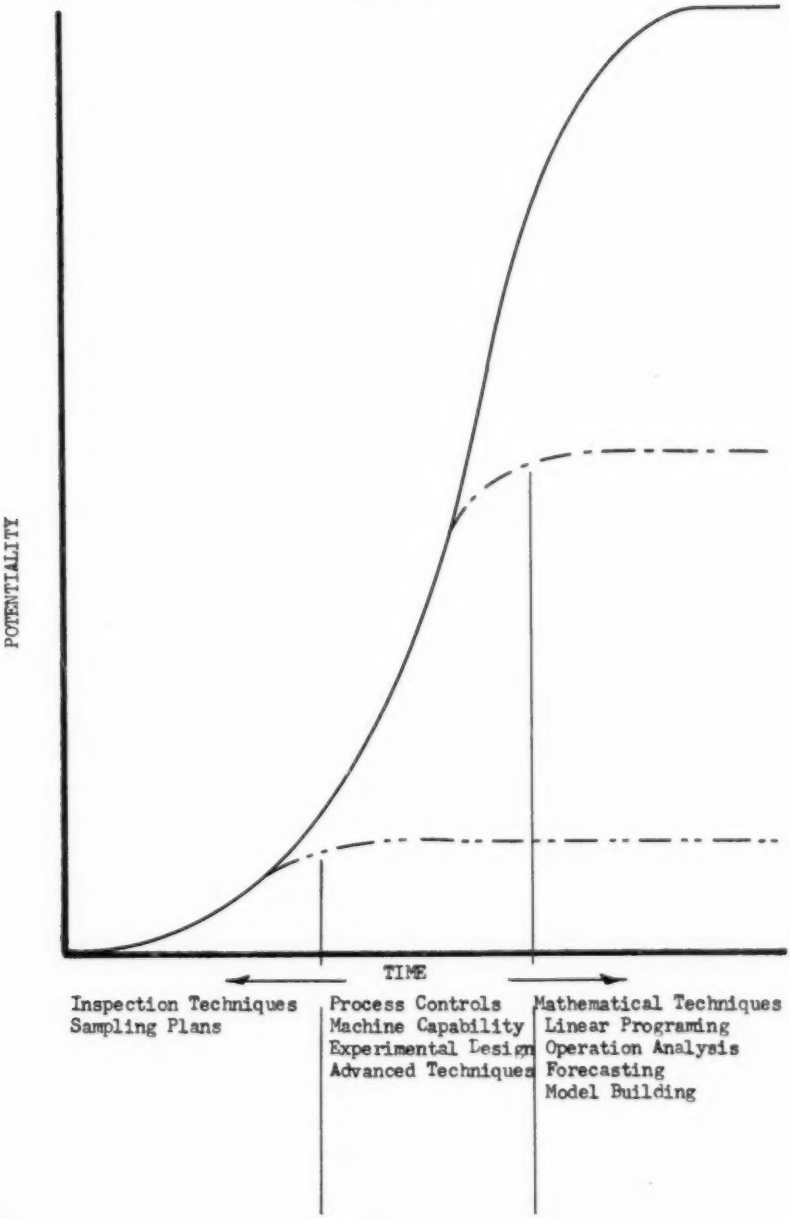
A. Within The Company
   1. seminars directed by members of the engineering group
   2. seminars directed by qualified consultants

B. Outside The Company - left to the initiative of the man

II. Supervisory Training

Attendance at conferences designed to foster foremen and supervisory abilities is required of the above average technician.

GROWTH CURVE



FREQUENCY DISTRIBUTIONS AND CHEMICAL REACTIONS

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Department of Chemistry
Ontario Research Foundation

1. Introduction

Nearly all the fundamental concepts of chemistry are tied up in some way with probabilistic and statistical ideas. Even to review the ways in which frequency distributions and chemical reactions can be related would be far beyond the scope of an article such as this. Therefore, this discussion will be limited to relations between the amounts of the reactants entering into a chemical reaction and the amounts of the products formed.

Looked at from this point of view only, various classes of chemical reactions can be arranged in order of increasing complexity; the simplest requiring no appeal to statistical models and frequency distributions, the more complex being incapable of accurate description without recourse to these devices. Such a series can be illustrated by the following examples.

2. Simple, Stoichiometric

To illustrate the simplest class, the following reaction can be taken as an example.

REACTANTS				PRODUCT
Fe	+	S	⟶	FeS
Iron		Sulphur		Iron Sulphide

This is a favorite in high school courses. If just the right amounts of reactants are heated, a reaction starts and goes to completion. Iron sulphide is the only product and no reactants are left over. The reaction is between two pure solids and the product is a solid.

In most chemical reactions, especially in organic chemistry, the reaction does not go to completion and unwanted reactions occur. The result is a certain amount of the desired product plus several by-products and unused reactants. Attention is often centered on the "yield" of the reaction, with little consideration being given to the unwanted materials and how they arise.

In contrast, we may consider our next class in which all reactants and products are considered.

3. Homogeneous, Mass Law

In this class, we might put a reaction of the type

REACTANTS			PRODUCT		BY-PRODUCTS
C_2H_5OH	+	CH_3-COOH	⟶ CH_3-$COOC_2H_5$	+	H_2O
alcohol		acid	ester		water

Here we have an alcohol and an acid reacting to form an ester and water. This is called an esterification: the acid is said to esterify the alcohol. All the reactants and products are mutually soluble, colorless liquids, and without special tests it would be difficult to realize that such a reaction was occurring in a flask.

If you start with the ester and water under the same conditions, the reaction goes the other way. It is then called a hydrolysis. It will be obvious that under these conditions neither reaction will go to completion, but an equilibrium will be reached where the two reactions just balance.

If, now, you add more alcohol or acid, you will drive the reaction to the right; if more ester or water, the reaction will go towards the left. In either case a new equilibrium is reached. Thus, if you increase the concentration of any of the four substances, the equilibrium shifts so as to use up that substance.

It is interesting that in 1867, Guldberg and Waage, using what was really a statistical kind of reasoning, decided that the rate at which the reaction went in either direction depended on the concentration of the substances capable of reacting in that direction. For example, if, in a given volume, you doubled the number of molecules of one reactant and halved that of the other, the rate of reaction was unaffected. This led to the classical Mass Law which states that at equilibrium

$$\frac{(\text{ester}) \times (\text{water})}{(\text{alcohol}) \times (\text{acid})} = \text{constant}$$

where the bracketed quantities are concentrations expressed in appropriate units.

Now, one could take the concentrations (or better the number of molecules) of each of the four categories, alcohol, acid, ester, and water, at any given time, plot them as a frequency distribution, and watch how the frequency distribution changed with time. This is essentially how Guldberg and Waage thought about the problem although they may not have used this method of representation.

4. Esterification of Glycerine

We can add another step of complexity by using a more complicated alcohol, such as glycerine, and reacting it with an acid, such as stearic acid.

Glycerine has the formula

$$\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

so that a glycerine molecule consists of three alcohol groups tied together. Each glycerine molecule in an experiment then has the possibility of ending up with none, one, two or three of its alcohol groups

esterified by stearic acid. Under the right conditions and with provision for the continuous removal of the water formed, all the stearic acid will react, unless present in excess of the amount required for complete esterification of all alcohol groups present. It might be thought that if just two-thirds of the acid required for complete esterification were used that the product would consist wholly of the ester having two stearic groups but this is not the case. The result of all such experiments is a mixture of all three possible esters and some unreacted glycerine - in other words, a frequency distribution.

At first chemists interested in making one of these esters regarded the others as unwanted by-products. However, some twenty years ago*, one statistically-minded chemist set up a statistical model. He supposed that the three alcohol groups in a glycerine molecule had equal probabilities of being esterified. This led to a binomial frequency distribution of glycerine molecules having none, one, two or three stearic groups attached. For example, if half the acid required for complete esterification were used, glycerine molecules having none, one, two and three stearic groups would be in the proportions 1, 3, 3, and 1 respectively. By experiments in which the ratio of alcohol to acid was varied, it was shown that the amounts of the four possible products followed this binomial law.

So here we had a case where the result of a reaction was a frequency distribution and where a statistical model helped in understanding what at first appeared to be a complicated situation.

Unfortunately, chemists paid more attention to the particular statistical model used in this and similar cases than to this general method of approach. They seemed to assume that the "statistical approach" was limited to a model which implied that all points of chemical attack on a molecule were equally likely.

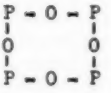
As an example where this model was not suitable, we can consider the hydrolysis of polyphosphates.

5. Hydrolysis of Polyphosphates

Since our examples from now on will be drawn from polyphosphate chemistry, a few words of introduction are in order.

Polyphosphate molecules are built around a skeleton consisting of alternate phosphorus and oxygen atoms, the P - O - P combination being called an "oxygen bridge". There is an infinite series of polyphosphates having a linear skeleton consisting of alternate phosphorus and oxygen atoms, and also two known polyphosphates having a ring skeleton. The linear polyphosphates are called ortho-, pyro-, tri-, tetra-, etc. phosphate when they have one, two, three, four, etc. phosphorus atoms in their skeleton. The ring polyphosphates are distinguished by the suffix meta-. Thus, we have trimetaphosphate and tetrametaphosphate having three and four phosphorus atoms in a ring. For example

* The writer is now unable to find the reference.

Linear Polyphosphates	P ortho-	P - O - P pyro-	P - O - P - O - P etc. tri-
Ring Polyphosphates			

Now, under certain conditions an oxygen bridge is attacked by water as follows:

$$H - O - H + - P - O - P - \longrightarrow - POH + - POH$$

This is called hydrolysis.

For our next example, let us consider the hydrolysis of tetraphosphate.

$$P - O - P - O - P - O - P$$

This has three oxygen bridges. If all these bridges are equally open to attack, the immediate products of hydrolysis would consist of molecules of ortho-, pyro-, and tri- in equal numbers. Before adequate methods of analysis were available, it was sometimes assumed that all hydrolysis of phosphates followed this pattern.

However, using the new filter-paper chromatographic methods, it is possible to show that the middle oxygen bridge is probably not attacked at all, the immediate products being tri- and ortho- within the limits of accuracy of the analysis. Consequently some other statistical model is needed.

6. Hydrolysis of Phosphate Glasses

As the next example in our series, let us consider a case where one starts and ends with a frequency distribution. The hydrolysis of a sodium phosphate glass is a good example.

Over a certain range of Na/P ratios, it is possible to melt a mixture of sodium phosphates to a homogeneous liquid, which, if cooled rapidly enough, does not crystallize but yields a clear homogeneous glass. If such a glass is dissolved in water and analyzed by paper chromatographic methods, it is found to consist largely of a frequency distribution of linear polyphosphates, but with practically no orthophosphate. Depending on the composition, up to about 7 per cent ring phosphates may be present.

Now, we have seen that tetraphosphate hydrolyzes almost entirely by splitting ortho- groups off the end of the molecule. The question naturally arises as to whether the higher members of the series hydrolyze in this way or whether the longer molecules tend to break in the center. Since the polyphosphates above the tetraphosphate have not yet been crystallized from solution and can be separated from each other only in small amounts as yet, this question might appear unanswerable.

However, we can make a phosphate glass having no orthophosphate and not too much of the lower members of the series. It can be dissolved in water and analyzed by paper chromatography to give an initial frequency distribution. Then it can be hydrolyzed in solution and the solution analyzed again. If the hydrolysis occurs largely by splitting off ortho- groups from the ends of molecules, then the ortho- content should build up rapidly but not much change occur in the concentration of the lower members of the series, since each category would gain about as much from the next higher category as it would lose to the next lower.

In this case we start and end with a frequency distribution. A typical result is shown in Figure 1.

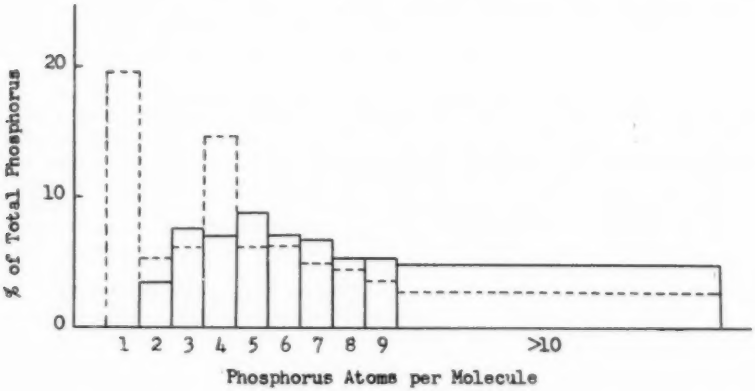


Figure 1. Frequency Distribution of a Phosphate Glass Before —— and After ---- Partial Hydrolysis.

It will be seen that three categories 1 (ortho-), 2 (pyro-), and 4 (tetra-) have increased but all others have decreased. The large increase in ortho- shows that much of the hydrolysis is occurring by the splitting off of ortho-groups, as suggested. The small increase in pyro- is explainable on the same hypothesis, since pyro- hydrolyzes very slowly under the conditions of the experiment, so there is a hold-up in this category. The increase in tetra- required some other explanation. More extensive analyses showed that this increase was not tetraphosphate but was trimeta-, a ring phosphate which was being formed from the very long molecules. Thus, the comparison of the initial and final frequency distribution showed that the polymers longer than tetraphosphate hydrolyzed both by splitting off of ortho-groups and by the formation of trimeta- rings.

7. Reactions Between Frequency Distributions

To complete our series, we should discuss a case in which each of

two or more reactants can be represented by frequency distributions. If two sodium phosphate glasses represented by quite different frequency distributions are melted together, a glass is produced having still another frequency distribution. However, work to date shows that the same glass would be produced from any mixture of sodium phosphates having the same overall Na/P ratio, so such an example has not much interest from a chemical point of view unless the rate at which equilibrium is reached is under study. Consequently, examples for this class of complexity will have to be sought elsewhere.

8. Summary

The writer has endeavored to show that in the mere matter of dealing with the amounts of reactants and products of a chemical reaction, frequency distributions can be of considerable assistance. Paper chromatographic methods which enable such distributions to be analyzed will make this approach more useful in the future.

THE APPLICATION OF STATISTICS TO SIMPLE FIXED-GAGE DESIGN

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What should be allowed for the gage maker's tolerance and wear allowance on a gage? This question has confronted anyone who has ever been concerned with specifying or designing a solid, non-adjustable instrument, such as a plug gage or fixed snap gage. While there are various "rules of thumb" that can be used in obtaining an answer to the above, the successful use of statistics as a decision making device in other areas indicates that at least a partial answer to the problem can be obtained through statistical analysis.

While the term "statistics" may denote merely a collection of data, it may also denote methods used in the analysis of data, or the interpretation of numerical data. When applying the concept of statistics to industrial control, data is collected from a process; then statistical measures are used in evaluating the data.

These statistical measures are a convenient means of measuring variation. Since variation is inherent to some degree in all products, tolerances are normally established for a particular part or dimension. The assumption is made that the particular machine and skills assigned to produce the part are capable of holding this tolerance. As this variation is seemingly inevitable, the pattern that it follows when produced by a controlled process is the bell-shaped or normal curve, shown in Fig. 1.

By way of additional review, the normal curve is divided into six separate areas. Using a table of areas of the normal curve, the various standard deviations indicated enclose the per cent of area listed:

1 standard deviation = 68.26 per cent
2 standard deviation = 95.44 per cent
3 standard deviation = 99.73 per cent

This knowledge, coupled with other statistical techniques, permits the evaluation of the percentages which may be falling outside tolerance limits, or conversely, parts falling within. However, for this application probability paper (1) will be used wherein the normal curve assumes a straight line when plotted, Fig. 2. Using this paper and drawing a line from the upper left-hand corner to the lower right-hand corner, or vice versa, the function of the normal curve is duplicated and the areas included under that curve can be read on the ordinates scale.

Any particular scale desired can be constructed on the abscissa. In this case a scale for a part having a tolerance of ± 0.001 has been selected to fit the existing conditions; namely, that the process is capable of producing parts within the specified tolerance and centered, and that 99.73 per cent of the parts will fall within the specifications. This is accomplished by allowing one tolerance limit to intersect our straight line at 00.135 per cent and the other tolerance limit to intersect at 99.865 per cent. The difference

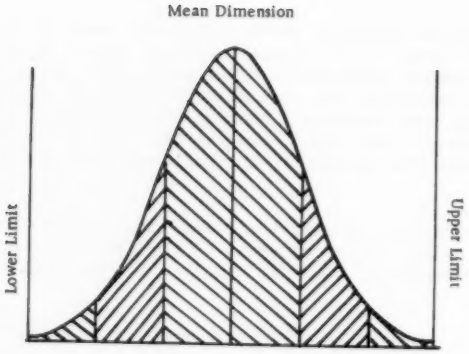


Fig. 1

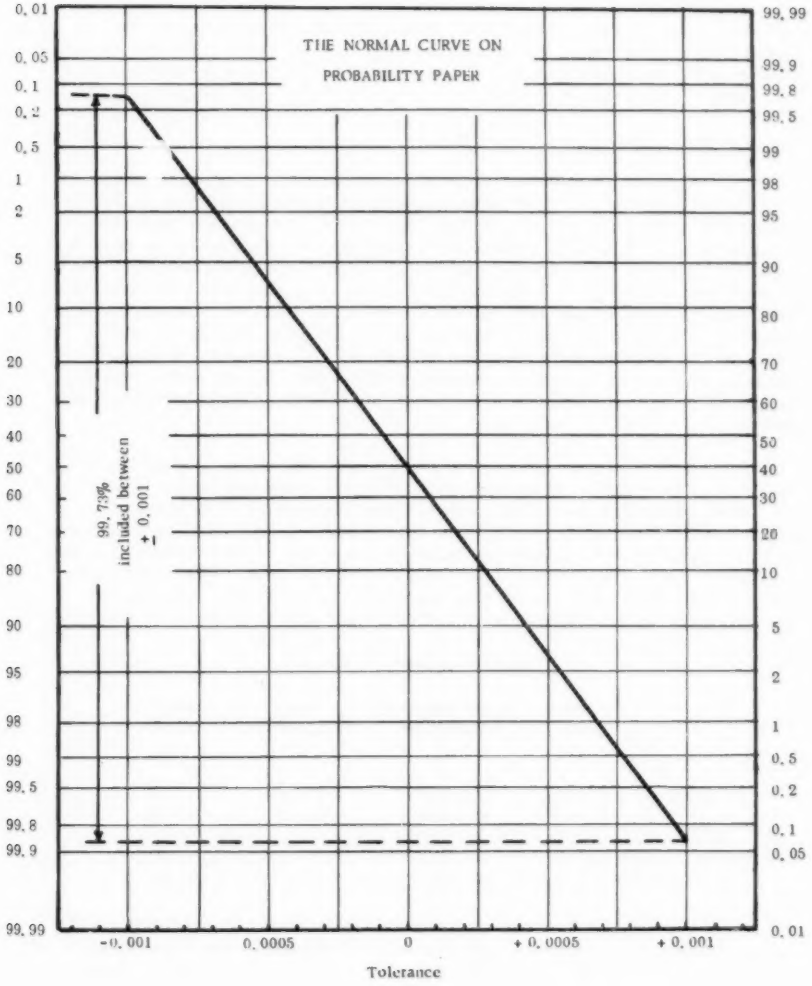

THE NORMAL CURVE ON
PROBABILITY PAPER
99, 73%
included between
± 0, 001
0, 01
0, 05
0, 1
0, 2
0, 5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99, 5
99, 8
99, 9
99, 99
99, 99
99, 9
99, 8
99, 5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0, 5
0, 2
0, 1
0, 05
0, 01
-0, 001
0, 0005
0
+ 0, 0005
+ 0, 001
Tolerance

Fig. 2

between the two is 99.73 per cent.

Having taken a rather brief look at the application of statistics to industrial processes, the next step is to consider some of the prevalent practices in fixed-gage design used in industry today. The methods of selecting and designing gaging may be divided into two primary classifications. One is the bilateral theory of gaging and the other the unilateral theory. There are modifications of these theories, but a brief explanation of only the bilateral and unilateral systems will be sufficient to illustrate this particular application, Fig. 3.

The Bilateral Theory of Tolerances

The bilateral theory of tolerances offers three possibilities as the ultimate result of gage making. One is that the gage will be within the work tolerance with the result that acceptable parts may be rejected. The second possibility is that the gage will be made to the size specified and as soon as wear occurs defective material will be accepted. The third possibility is that the gage will be made outside the work tolerance and defective material will be accepted immediately and continue to be accepted as long as the gage is in use. Of these three alternatives the first is probably the most desirable. However, using bilateral tolerances, it is never certain which one of the conditions will exist until the gage is received and checked.

To illustrate this concept consider the following problem: To design a plug gage for gaging a $0.500^{+0.002}_{-0.000}$ inches diameter hole. The total tolerance is 0.002 inches. The gage maker's tolerance, using standard practice, is 10 per cent of the total working tolerance or 0.0002 inches. Standard practice is to allow an additional 0.0001 or 0.00005 inches as wear allowance for the "go gage" (2). This is shown graphically in Fig. 4, and possible sizes of the "go" and "not-go" plug gages under maximum conditions are tabulated in Table 1.

TABLE 1 SIZES OF GAGES

	Basic size, in.	Gage Maker's tolerance, in.	Wear allowance, in.	Gage size, in.
Go gage	(0.500	-0.0001	+0.0001	0.5000
	(0.500	+0.0001	+0.0001	0.5002
Not-go gage	(0.502	-0.0001		0.5019
	(0.502	+0.0001		0.5021

Note that these are the maximum conditions which may occur. If the gage maker does not utilize his full tolerance, the final gage size may be either slightly larger or smaller. Referring to the go gage the 0.5000-in. gage would accept parts outside the work tolerance almost immediately. The 0.5002-in. gage will reduce our acceptance of parts that are within work tolerance and permits a wear of 0.0002 in. before it is unusable. On the not-go gage the 0.5019-in. will give adequate protection. The 0.5021-in. gage will accept parts outside our specified tolerance until at least 0.0001 in. is worn off.

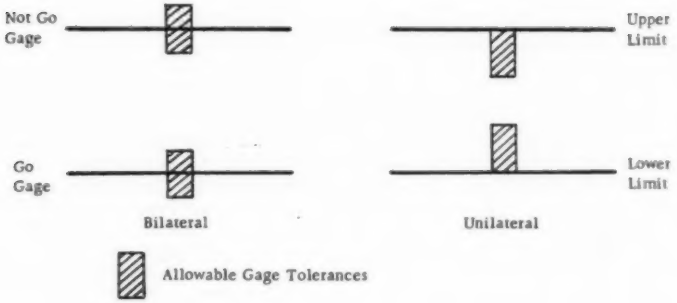

Not Go Gage
Upper Limit
Go Gage
Lower Limit
Bilateral
Unilateral
Allowable Gage Tolerances

Fig. 3

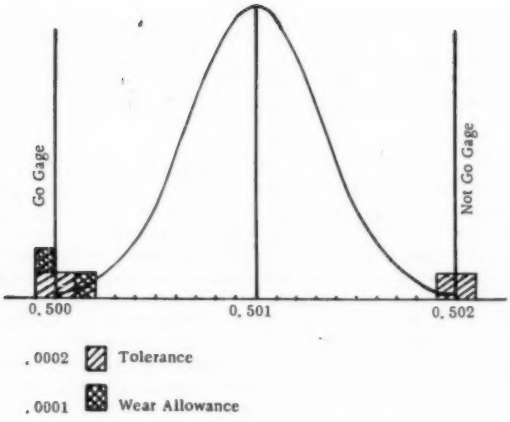

Go Gage
Not Go Gage
0.500
0.501
0.502
.0002 Tolerance
.0001 Wear Allowance

Fig. 4

This summarizes existing conditions using the bilateral concept, although as previously pointed out, the sizes are not usually known until the gage is received.

The Unilateral Theory of Tolerances

Using the same problems as used for bilateral tolerances the concept of unilateral tolerances will be illustrated. Usually there is only one possibility when using this theory; if the unilateral tolerances are applied within the work tolerance, acceptable parts will be rejected, but this is normally preferable to accepting parts outside the work tolerance. Using the previous problem, a plug gage for gaging a $0.500^{+0.002}_{-0.000}$ inches diameter hole, a 10 per cent gage maker's tolerance or 0.0002 inches is applied. In addition to this, 10 per cent is applied for wear allowance to the go gage only (3). This concept is illustrated in Fig. 5 and possible sizes of go and not-go gages under maximum conditions are tabulated in Table 2.

TABLE 2 SIZES OF GAGES FOR MAXIMUM CONDITIONS

	Basic size, in.	Gage Maker's tolerance, in.	Wear allowance, in.	Gage size, in.
Go gage	0.500	+0.0002	+0.0002	0.5004
Not-go gage	0.502	-0.0002		0.5018

It should be re-emphasized that these are maximum conditions and exist only in the event that the gage maker utilizes his total tolerance. However, wear allowance always should be provided as specified and means that there will be parts rejected that are within the acceptable tolerance limits.

The primary question then, if the unilateral method of applying tolerances is used, is determining the percentage of parts that will be rejected by the go and not-go gages. This is essentially the tie-in to the introduction of this paper wherein statistics were discussed and also the method of developing the normal curve on probability paper.

Reference is now made to Fig. 6. Here is illustrated the application of the concept which utilizes the statistical approach in determining the percentage of parts rejected by the fixed gage. The specifications are $0.500^{+0.002}_{-0.000}$ and this tolerance is again constructed on the abscissa. A diagonal is drawn intersecting the limits of the tolerance at 00.13 per cent. If the tolerance and wear allowance on the go gage is applied in a unilateral direction, using maximum values, a total of 20 per cent of the work tolerance or 0.0004 inches is cut off. Erecting a vertical line intersecting the diagonal, and referring to the ordinate scale, a total of 3.6 per cent is found to be cut off. This minus 0.13 per cent equals a total of 3.47 per cent of the acceptable parts rejected by the go gage.

Since the not-go gage does not require a wear allowance ordinarily, a total of 10 per cent of the work tolerance or 0.0002 in. is taken for the gage maker's tolerance. Applying this unilaterally and again erecting a vertical intersecting the diagonal a total of 0.82

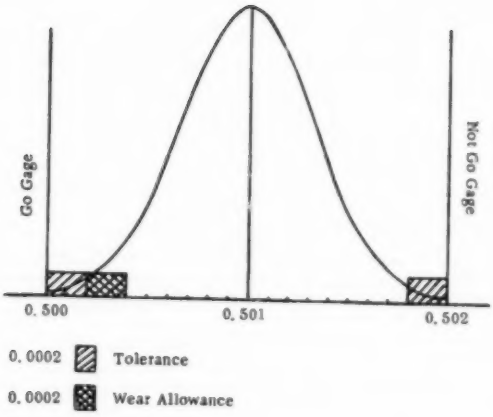

Go Gage
Not Go Gage
0. 500
0. 501
0. 502
0. 0002 Tolerance
0. 0002 Wear Allowance

Fig. 5

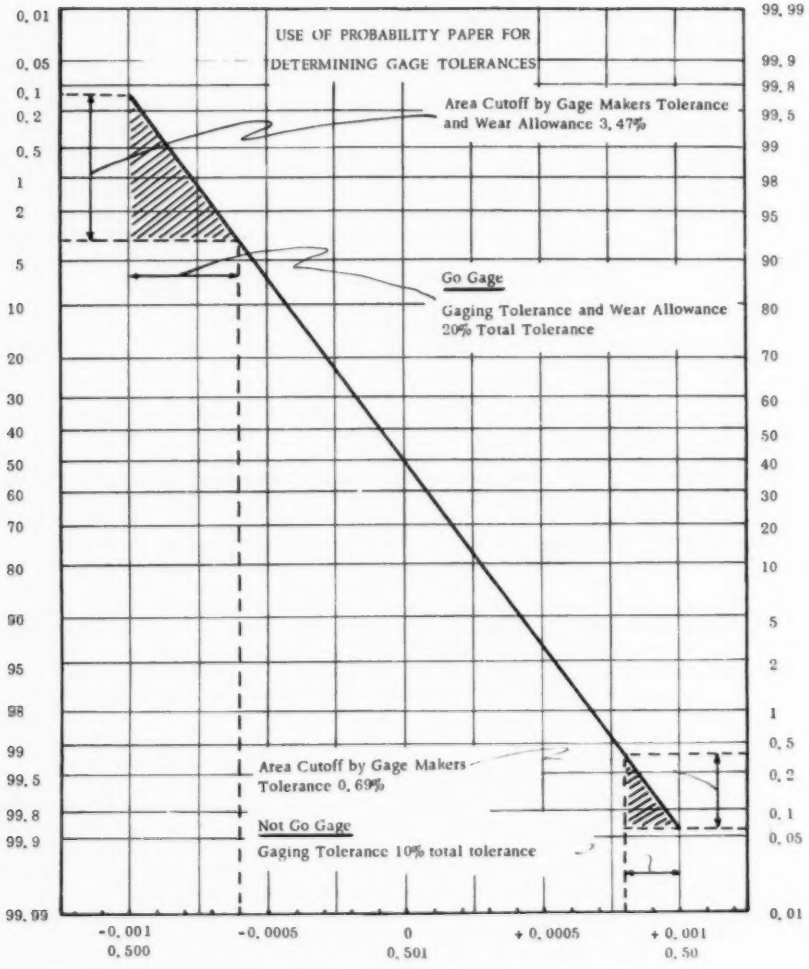

USE OF PROBABILITY PAPER FOR
DETERMINING GAGE TOLERANCES
Area Cutoff by Gage Makers Tolerance
and Wear Allowance 3.47%
Go Gage
Gaging Tolerance and Wear Allowance
20% Total Tolerance
Area Cutoff by Gage Makers
Tolerance 0.69%
Not Go Gage
Gaging Tolerance 10% total tolerance
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
-0.001
0.500
-0.0005
0
0.501
+0.0005
+0.001
0.50

Fig. 6

per cent is found to be cut off. This minus 0.13 per cent equals a total of 0.69 per cent of the acceptable parts rejected by the not-go gage. Adding these two areas together, or 3.47 plus 0.69 per cent, gives a total of 4.16 per cent of acceptable parts rejected by these gages when new, assuming the material is produced and centered within blue-print specifications.

The foregoing follows the ordnance method of applying gage maker's tolerance and wear allowance and represents the maximum conditions which would be encountered. For this size range (0.501) and total tolerance of 0.002 in. a Class Z gage could be utilized which has a gage maker's tolerance of 0.00010 in. (using 10 per cent rule for establishing gage maker's tolerance). This would give a total of 0.00020 in. when both go and not-go gages are used.

Referring to Fig. 7, the picture is observed to be somewhat altered. Still using the same wear allowance of 0.0002 in., the revised tolerance and wear allowance combined will result in rejecting 1.85 per cent of the parts. Cost for this Class Z gage would be $5.18 according to a prominent manufacturing concern's price list. If a Class Y gage were specified in this instance, tolerance for each gage is 0.00007 in. This gage would reject a total of 1.45 per cent of the good parts produced and the cost would be $5.75.

To illustrate, consider a hypothetical case involving the inspection of 10,000 units. If these are hardened-steel gages, a rough estimate of the gage-wear life with a 0.0001 in. wear allowance would be approximately 2000 pieces (4). Since this wear allowance is 0.0002 in. the gage should be useful for 4000 pieces. This means 2-1/2 gages are required to inspect the lot. Suppose that reinspection of rejected material amounts to $0.015/each. The results of these calculations are summarized below in Table 3.

TABLE 3 GAGE COSTS COMPARED

Gage	Cost	Savings	Cost of reinspection	Savings
Class Z	$12.95	$1.42	$2.925	$
Class Y	14.37		2.175	0.750

This shows that the difference in gage cost if $1.42 in favor of the Class Z gage. However, on reinspection cost the Class Y gage results in a greater savings amounting to $0.750. Net savings remain in favor of the Class Z gage in the amount of $0.67.

In the foregoing example there seems to be a very slight probability of ever reflecting substantial savings by utilizing a smaller gaging tolerance. However, savings may be possible if the wear allowance is varied. Previously a wear allowance of 0.0002 in. was used and the Class Z gage rejected 1.95 per cent of the parts. If this is reduced to 0.0001 in. wear allowance 0.84 per cent of the parts would be rejected. Reducing the wear allowances means that now five gages are required, each gage having a wear life of 2000 pieces. Again summarizing in Table 4.

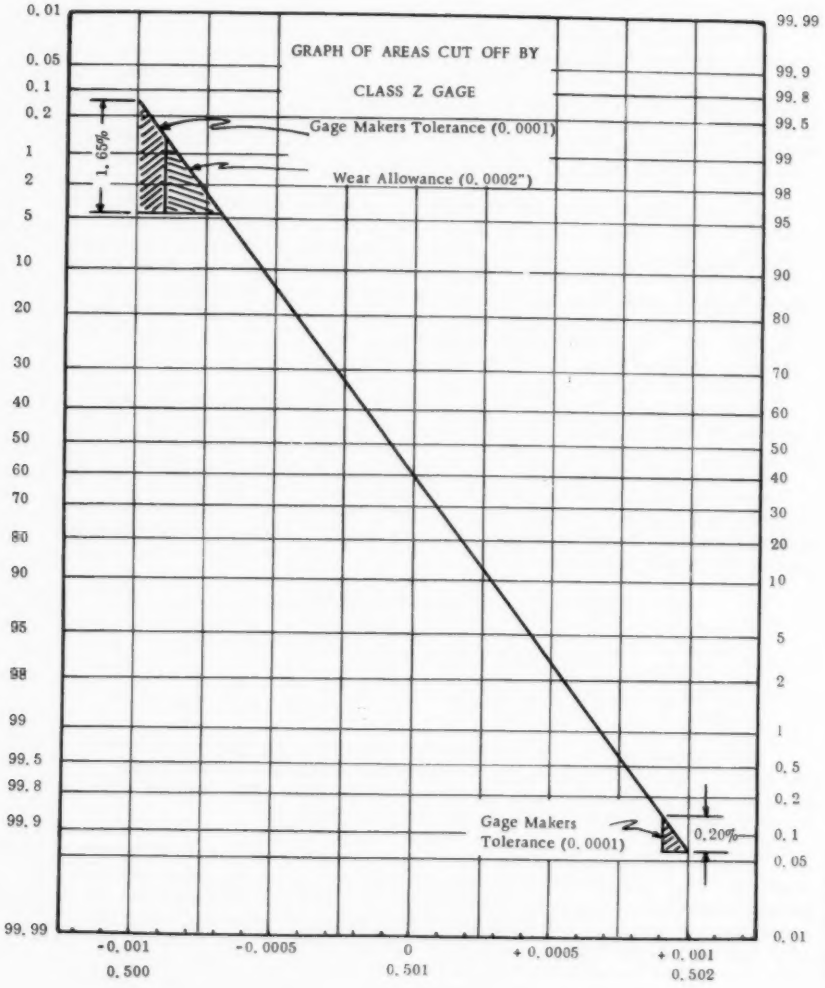

GRAPH OF AREAS CUT OFF BY
CLASS Z GAGE
Gage Makers Tolerance (0. 0001)
Wear Allowance (0. 0002")
1. 65%
Gage Makers
Tolerance (0. 0001)
0. 20%
0. 01
0. 05
0. 1
0. 2
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99. 5
99. 8
99. 9
99. 99
99. 99
99. 9
99. 8
99. 5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0. 5
0. 2
0. 1
0. 05
0. 01
-0. 001
0. 500
-0. 0005
0
0. 501
+ 0. 0005
+ 0. 001
0. 502

Fig. 7

TABLE 4 GAGE COSTS WITH REDUCED WEAR ALLOWANCE

Gage	Total gage cost	Difference	Cost of reinspection	Difference
0.0002 w/a	$12.95	$12.95	$2.925	$
0.0001 w/a	25.90		1.26	1.665

In this example it is more practical to allow a 0.0002 inch wear allowance. Savings are $11.285. It seems obvious now, that if an additional wear allowance is provided on the gages, the gage inspects a much larger number of parts with a relatively small increase in reinspection cost.

To evaluate this concept in more detail it is of benefit to construct a minimum cost point graph showing how much wear allowance is economically justified. For convenience Table 5 has been compiled, showing the total percentage of parts rejected for various combinations of gage maker's tolerance and wear allowance. Using the previous problem (hole size $0.500\ ^{+0.002}_{-0.000}$) and a production of 30,000 pieces, the data can be tabulated as shown in Table 6. This does not have to be done in every analysis and is presented here primarily for clarity. The first five columns are taken directly from Table 5. The per cent rejected by the not-go gage has been altered to conform with the gage maker's tolerance for a Class Z gage in this size range, and is taken from Fig. 7.

For this size range 0.500 in., a work tolerance of 0.002 in., and using the 10 per cent rule, the gage maker's tolerance is 0.0002 in. Since this much latitude is not given the gage maker in any classification, a "Class Z" gage with a gage maker's tolerance of 0.0001 in. can be used and the extra 0.0001 in. applied to the wear allowance. This will not affect the total wear allowance plus gage maker's tolerance since it merely involves adding to the former and subtracting from the latter. However, it will affect the number of gages required, based on the wear life noted in Table 6. For example, the first wear allowance of 0.00008 in. will be increased to 0.00018 in. and instead of 12.5 gages for the 30,000 pieces the gages required would be

$$\frac{1.8}{1} = \frac{X \text{ pieces}}{2000 \text{ pieces}}, \quad X = 3600 \text{ pieces}$$

$$\frac{30{,}000}{3600} = 8.33$$

The number of gages for the remaining conditions are shown in Table 6, and are derived in a similar way.

The cost per gage is taken from a 1952 edition of the Van Keuren catalog and is not intended to reflect current prices. The prices are for precision-lapped, Class Z gages and are corrected for the discount allowed when buying more than one. Total gage cost is the result of multiplying the last two columns. This curve can now be plotted as illustrated in Fig. 8. Total cost is plotted on the ordinate and percentage of rejections is plotted on the abscissa.

TABLE 5 TOTAL PERCENTAGE OF PARTS REJECTED FOR VARIOUS COMBINATIONS OF GAGE MAKER'S TOLERANCE AND WEAR ALLOWANCE

Total Work Tolerance	Gage Makers Tolerance	Wear Allowance	Total	% Parts Rejected	Gage Makers Tolerance	% Parts Rejected	Total % Rej.
0.0002	0.00002	0.00001	0.00003	1.66	0.00002	0.69	2.35
		0.00002	0.00004	3.46		0.69	4.15
		0.00003	0.00005	6.55		0.69	7.24
		0.00004	0.00006	11.38		0.69	12.07
0.0003	0.00003	0.000015	0.000045	1.66	0.00003	0.69	2.35
		0.00003	0.00006	3.46		0.69	4.15
		0.000045	0.000075	6.55		0.69	7.24
		0.000069	0.00009	11.38		0.69	12.07
0.0004	0.00004	0.000016	0.000056	1.41	0.00004	0.69	2.10
		0.00002	0.00006	1.66		0.69	2.35
		0.000032	0.000072	2.61		0.69	3.30
		0.00004	0.00008	3.46		0.69	4.15
		0.00006	0.00010	6.55		0.69	7.24
		0.00008	0.00012	11.38		0.69	12.07
0.0005	0.00005	0.00002	0.00007	1.41	0.00005	0.69	2.10
		0.00004	0.00009	2.61		0.69	3.30
		0.00005	0.00010	3.46		0.69	4.15
		0.00007	0.00012	5.81		0.69	6.50
		0.00009	0.00014	9.21		0.69	9.90
		0.00010	0.00015	11.38		0.69	12.07
0.0006	0.00006	0.000018	0.000078	1.19	0.00006	0.69	1.88
		0.00003	0.00009	1.66		0.69	2.35
		0.00006	0.00012	3.46		0.69	4.15
		0.00009	0.00015	6.55		0.69	7.24
		0.00012	0.00018	11.38		0.69	12.07
0.00065	0.000065	0.000026	0.000091	1.41	0.000065	0.69	2.10
		0.000052	0.000117	2.61		0.69	3.30
		0.000078	0.000143	4.52		0.69	5.21
		0.000104	0.000169	7.36		0.69	8.05
		0.00013	0.000195	11.38		0.69	12.07
0.0007	0.00007	0.000014	0.000084	1.00	0.00007	0.69	1.69
		0.000035	0.000105	1.66		0.69	2.35
		0.00007	0.00014	3.46		0.69	4.15
		0.000105	0.000175	6.55		0.69	7.24
		0.00014	0.00021	11.38		0.69	12.07
0.0008	0.00008	0.000024	0.000104	1.19	0.00008	0.69	1.88
		0.000040	0.00012	1.66		0.69	2.35
		0.00008	0.00016	3.46		0.69	4.15
		0.00012	0.00020	6.55		0.69	7.24
		0.00016	0.00024	11.38		0.69	12.07
0.0009	0.00009	0.000018	0.000108	1.00	0.00009	0.69	1.69
		0.000045	0.000135	1.66		0.69	2.35
		0.00009	0.00018	3.46		0.69	4.15
		0.000135	0.000225	6.55		0.69	7.24
		0.00018	0.00027	11.38		0.69	12.07

Total Work Tolerance	Gage Makers Tolerance	Wear Allowance	Total	% Parts Rejected	Gage Makers Tolerance	% Parts Rejected	Total % Rej.
0.0010	0.00010	0.00002	0.00012	1.00	0.00010	0.69	0.69
		0.00004	0.00014	1.41		0.69	2.10
		0.00006	0.00016	1.94		0.69	2.63
		0.00008	0.00018	2.61		0.69	3.30
		0.00010	0.00020	3.46		0.69	4.15
		0.00014	0.00024	5.81		0.69	6.50
		0.00018	0.00028	9.21		0.69	9.90
		0.00020	0.00030	11.38		0.69	12.07
0.0012	0.00012	0.00006	0.00018	0.66	0.00012	0.69	2.35
		0.00012	0.00024	3.46		0.69	4.15
		0.00018	0.00030	6.55		0.69	7.24
		0.000216	0.000336	9.21		0.69	9.90
		0.00024	0.00036	11.38		0.69	12.07
0.0013	0.00013	0.000065	0.000195	1.66	0.00013	0.69	2.35
		0.00013	0.00026	3.46		0.69	4.15
		0.000195	0.000325	6.55		0.69	7.24
		0.000234	0.000364	9.21		0.69	9.90
		0.00026	0.00039	11.38		0.69	12.07
0.0015	0.00015	0.00003	0.00018	1.00	0.00015	0.69	1.69
		0.00009	0.00024	1.94		0.69	2.63
		0.00015	0.00030	3.46		0.69	4.15
		0.00021	0.00036	5.81		0.69	6.50
		0.00027	0.00042	9.21		0.69	9.90
		0.00030	0.00045	11.38		0.69	12.07
0.0016	0.00016	0.00008	0.00024	1.66	0.00016	0.69	2.35
		0.00016	0.00032	3.46		0.69	4.15
		0.00024	0.00040	6.55		0.69	7.24
		0.000288	0.000448	9.21		0.69	9.90
		0.00032	0.00048	11.38		0.69	12.07
0.0019	0.00019	0.000095	0.000285	1.66	0.00019	0.69	2.35
		0.00019	0.00038	3.46		0.69	4.15
		0.000285	0.000475	6.55		0.69	7.24
		0.00038	0.00057	11.38		0.69	12.07
0.002	0.00020	0.00008	0.00028	1.41	0.00020	0.69	2.10
		0.00016	0.00036	2.61		0.69	3.30
		0.00020	0.00040	3.46		0.69	4.15
		0.00024	0.00044	4.52		0.69	5.21
		0.00028	0.00048	5.81		0.69	6.50
		0.00032	0.00052	7.36		0.69	8.05
		0.00036	0.00056	9.21		0.69	9.90
		0.00040	0.00060	11.38		0.69	12.07
0.0024	0.00024	0.00012	0.00036	1.66	0.00024	0.69	2.35
		0.00024	0.00048	3.46		0.69	4.15
		0.00036	0.00060	6.55		0.69	7.24
		0.00048	0.00072	11.38		0.69	12.07
0.0025	0.00025	0.00010	0.00035	1.41	0.00025	0.69	2.10
		0.00020	0.00045	2.61		0.69	3.30
		0.00030	0.00055	4.52		0.69	5.21
		0.00040	0.00065	7.36		0.69	8.05
		0.00050	0.00075	11.38		0.69	12.07

Total Work Tolerance	Gage Makers Tolerance	Work Allowance	Total	% Parts Rejected	Gage Makers Tolerance	% Parts Rejected	Total % Rej.
0.0030	0.00030	0.00006	0.00036	1.00	0.00030	0.69	1.69
		0.00015	0.00045	1.66		0.69	2.35
		0.00030	0.0006	3.46		0.69	4.15
		0.00045	0.00075	6.55		0.69	7.24
		0.00054	0.00084	9.21		0.69	9.90
		0.00060	0.0009	11.38		0.69	12.07
0.0032	0.00032	0.00016	0.00048	1.66	0.00032	0.69	2.35
		0.00032	0.00064	3.46		0.69	4.15
		0.00048	0.00080	6.55		0.69	7.24
		0.00064	0.00096	11.38		0.69	12.07
0.0040	0.00040	0.00008	0.00048	1.00	0.00040	0.69	1.69
		0.00020	0.00060	1.66		0.69	2.35
		0.00032	0.00072	2.61		0.69	3.30
		0.00040	0.0008	3.46		0.69	4.15
		0.00048	0.00088	4.52		0.69	5.21
		0.00060	0.00100	6.55		0.69	7.24
		0.00072	0.00112	9.21		0.69	9.90
		0.00080	0.00120	11.38		0.69	12.07
0.0050	0.00050	0.00010	0.00060	1.00	0.00050	0.69	1.69
		0.00020	0.00070	1.41		0.69	2.10
		0.00030	0.00080	1.94		0.69	2.63
		0.00040	0.00090	2.61		0.69	3.30
		0.00050	0.00100	3.46		0.69	4.15
		0.00060	0.00110	4.52		0.69	5.21
		0.00070	0.00120	5.81		0.69	6.50
		0.00080	0.00130	7.36		0.69	8.05
		0.00090	0.00140	9.21		0.69	9.90
		0.00100	0.00150	11.38		0.69	12.07
0.0064	0.00064	0.00032	0.00096	1.66	0.00064	0.69	2.35
		0.00064	0.00128	3.46		0.69	4.15
		0.00096	0.00160	6.55		0.69	7.24
		0.00128	0.00192	11.38		0.69	12.07
0.0080	0.00080	0.00016	0.00096	1.00	0.00080	0.69	1.69
		0.00040	0.00120	1.66		0.69	2.35
		0.00064	0.00144	2.61		0.69	3.30
		0.00080	0.00160	3.46		0.69	4.15
		0.00120	0.00200	6.55		0.69	7.24
		0.00144	0.00224	9.21		0.69	9.90
		0.00160	0.00240	11.38		0.69	12.07
0.0100	0.0010	0.0001	0.0011	0.83	0.0010	0.69	1.52
		0.0002	0.0012	1.00		0.69	1.69
		0.0004	0.0014	1.41		0.69	2.10
		0.0006	0.0016	1.94		0.69	2.63
		0.0008	0.0018	2.61		0.69	3.30
		0.0010	0.0020	3.46		0.69	4.15
		0.0014	0.0024	5.81		0.69	6.50
		0.0016	0.0026	7.36		0.69	8.05
		0.0018	0.0028	9.21		0.69	9.90
		0.0020	0.0030	11.38		0.69	12.07

Total Work Tolerance	Gage Makers Tolerance	Work Allowance	Total	% Parts Rejected	Gage Makers Tolerance	% Parts Rejected	Total % Rej.
0.0120	0.0012	0.00012	0.00132	0.83	0.0012	0.69	1.52
		0.00024	0.00144	1.00		0.69	1.69
		0.00048	0.00168	1.41		0.69	2.10
		0.00060	0.0018	1.66		0.69	2.35
		0.00096	0.00216	2.61		0.69	3.30
		0.0012	0.0024	3.46		0.69	4.15
		0.0018	0.0030	6.55		0.69	7.24
		0.00216	0.00336	9.21		0.69	9.90
		0.0024	0.0036	11.38		0.69	12.07
0.00140	0.0014	0.00014	0.00156	0.83	0.0014	0.69	1.52
		0.00028	0.00168	1.00		0.69	1.69
		0.00056	0.00196	1.41		0.69	2.10
		0.00070	0.00210	1.66		0.69	2.35
		0.00112	0.00252	2.61		0.69	3.30
		0.0014	0.0028	3.46		0.69	4.15
		0.0021	0.0035	6.55		0.69	7.24
		0.00252	0.00392	9.21		0.69	9.90
		0.0028	0.0042	11.38		0.69	12.07
*0.0160	0.0016	0.00016	0.00176	0.83	0.0016	0.69	1.52
		0.00032	0.00192	1.00		0.69	1.69
		0.00064	0.00224	1.41		0.69	2.10
		0.00080	0.0024	1.66		0.69	2.35
		0.00128	0.00288	2.61		0.69	3.30
		0.0016	0.0032	3.46		0.69	4.15
		0.0024	0.0040	6.55		0.69	7.24
		0.00288	0.00448	9.21		0.69	9.90
		0.0032	0.0048	11.38		0.69	12.07
*0.0200	0.0020	0.0002	0.0022	0.83	0.0020	0.69	1.52
		0.0004	0.0024	1.00		0.69	1.69
		0.0008	0.0028	1.41		0.69	2.10
		0.0010	0.0030	1.66		0.69	2.35
		0.0016	0.0036	2.61		0.69	3.30
		0.0020	0.0040	3.46		0.69	4.15
		0.0030	0.0050	6.55		0.69	7.24
		0.0036	0.0056	9.21		0.69	9.90
		0.0040	0.0060	11.38		0.69	12.07

Note: Since gage maker's tolerances for numerous nominal sizes and work tolerances exceed any values found in standard tables, use the gage makers tolerance for the classification selected and apply the remainder to the wear allowance. As can be seen this will not effect the combined gage makers tolerance and wear allowance, nor will it effect the total per cent rejected.

GAGE AND PRODUCTION DATA
TABLE 6

Work Tolerance 0.002"

Go Gage				Not-Go Gage		Total Per Cent Rejected	No. Gages* Reqd. to Inspect 10,000 pieces	Cost per Gage	Total Gage Cost
Gage Makers Tolerance	Wear Allowance	Total 1 + 2	Per Cent Rejected	Gage Makers Tolerance	Per Cent Rejected				
0.00020	0.00008	0.00028	1.41	0.00020	0.69	2.10	8.34	$3.90 †	$32.45
	0.00016	0.00036	3.61		0.69	3.30	5.78	4.125‡	23.75
	0.00020	0.00040	3.46		0.69	4.15	5.00	4.125	20.63
	0.00024	0.00044	4.52		0.69	5.21	4.42	4.125	18.13
	0.00028	0.00048	5.81		0.69	6.50	3.95	4.125	16.25
	0.00032	0.00052	7.36		0.69	8.05	3.57	4.125	14.65
	0.00036	0.00056	9.21		0.69	9.90	3.26	4.125	13.40
	0.00040	0.00060	11.38		0.69	12.07	3.00	4.125	12.38

*Based on hardened steel gage with approximate wear life of 2,000 pieces per 0.0001" wear allowance.

† Based on 6 gage quantity price.

‡ Based on 3 gage quantity price.

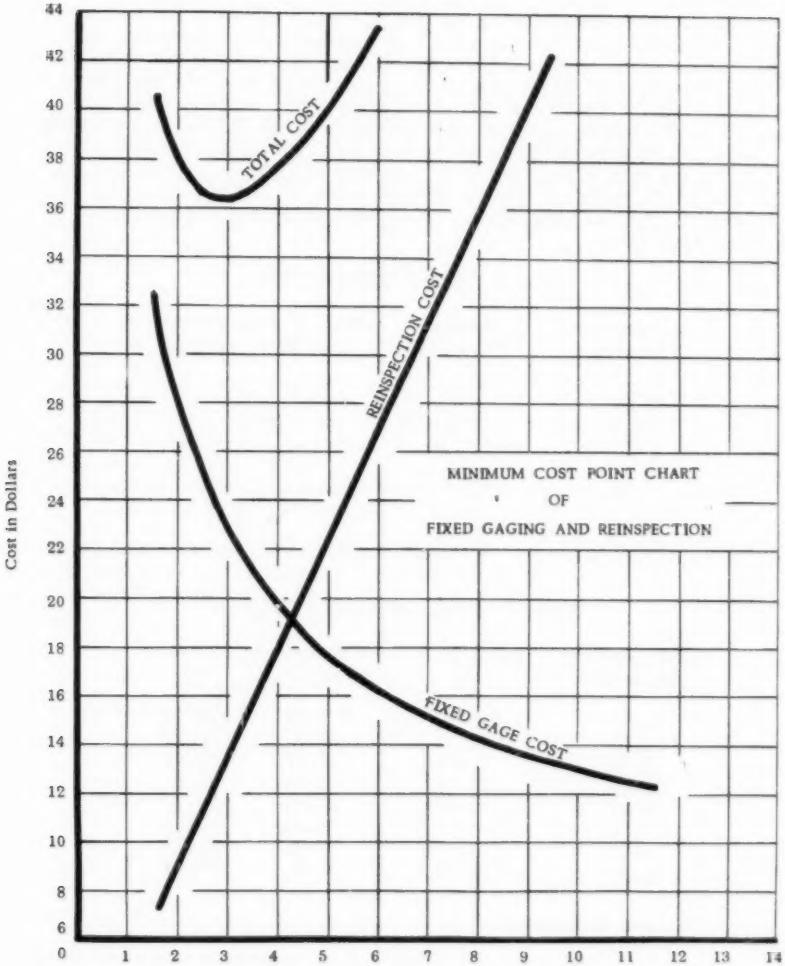

TOTAL COST
REINSPECTION COST
FIXED GAGE COST
MINIMUM COST POINT CHART
OF
FIXED GAGING AND REINSPECTION
Cost in Dollars
Per Cent Rejected
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Fig. 8

Reinspection. To determine the cost of reinspection curve some means should be found for setting a per-piece cost. This will be primarily labor, burden, and gaging expense in the majority of cases and may be determined from past experience under similar conditions. In this example an arbitrary figure of $0.015 per piece is selected for demonstration of the principle involved. These costs are tabulated in Table 7. The curve showing the reinspection costs is plotted in Fig. 8. Table 8 sums the costs of fixed gages and reinspection and Fig. 8 shows these costs in the form of a minimum-cost curve. This curve indicates that the minimum cost is achieved around 3 per cent rejected, and is plotted only to illustrate these costs graphically, since the information is obtainable in Table 8 and Table 6. Referring to these tables a rejection rate of 2.81 per cent indicates the need for 6.0 gages with a gage maker's tolerance of 0.0001 in. and a wear allowance of 0.00026 in. for a combined value of 0.00036 in. As can be observed, this is considerably more wear allowance than normally would be specified.

TABLE 7 COST OF REINSPECTION

Total per cent rejected	Number rejected	Cost of reinspection at $0.015/piece
1.61	4.83	$ 7.25
2.81	8.43	12.65
3.66	10.98	16.47
4.72	14.16	21.24
6.01	18.03	27.05
7.56	22.68	34.02
9.42	28.23	42.35
11.58	34.74	52.11

TABLE 8 TOTAL INSPECTION COST

Total per cent rejection	Total gage cost	Reinspection cost	Total cost
1.61	$32.45	$ 7.25	$39.70
2.81	23.75	12.65	36.40[a]
3.66	20.63	16.47	37.10
4.72	18.13	21.24	39.37
6.01	16.25	27.05	43.30
7.56	14.65	34.02	48.67
9.41	13.40	42.35	55.75
11.58	12.38	52.11	64.49

[a]Minimum-Cost point.

Alternative Solution. While the preceding problem illustrates one method of solution, an alternative method exists. For example, all values of per cent rejection by gages are conditions that exist only when a gage is new. As the gage wears, fewer and fewer parts are rejected, so possibly an average value of per cent rejections would be more realistic. This would result in less gage savings than under the conditions specified; however, if average values were used, additional wear allowance could be applied with the probability of

effecting the same or greater savings in gaging cost. The problem presented used maximum conditions throughout, with the thought that by so doing the designer is provided with additional protection. There are, however, mathematical means of determining the average per cent rejections for any particular gage size, and the use of these values would in no way alter the general method of solution.

Conclusion

Summarizing, since there are many variables connected with this analysis, i.e., the per cent rejections, the gage wear life (hardened steel, chrome, carbide, etc.), the gage cost (based on quantity needed), and the reinspection cost, there would be no great benefit in deriving a formula for solution. Each approach is individual and should be an analysis of individual needs. However, by following through these calculations, considerable savings should be possible. A last note of caution is given -- the process must be statistically in control, for this technique to be applied effectively.

References

1. Small grid lines in "probability paper" have been eliminated in the illustrations accompanying this presentation.

2. Quoted from "Inspection and Gaging", by C. W. Kennedy, Industrial Press, New York, N. Y., 1951.

3. Wear allowance is normally specified by the buyer. The 10 per cent used here would be a maximum in most cases.

4. Average value adopted from "Precision Measurement in the Metalworking Industry" -- Department of Education -- IBM Corporation.

PRODUCT SUPPORT IMPROVES RELIABILITY

Glenn L. Coates
Hughes Aircraft Company

This paper is intended to describe a portion of the over-all effort the Hughes Aircraft Company is putting forth to improve the performance and reliability of our equipment. It will cover mainly those operations directly concerned with or related to the support of the finished product as it leaves the Company on its way to the field, the collection of data resulting from these operations, and the utilization of this data to improve reliability.

Before we delve into the support considerations, however, I would first like to give you a brief insight into the over-all Company Reliability Program, then show how the support concept is tied into these operations.

To begin with, any effective reliability program will involve a basic objective; that reliability be inherent in the end item. The Hughes approach to this basic objective is to first set up standards in production and then establish test programs to see how we are meeting our goals. Since many of the variables to be considered in arriving at an acceptable level are not compatible, it is necessary to compromise. At present, we are specifying a "mean service life" as a minimum acceptable level of reliability. We then try to establish design objectives which will meet the acceptable level. Proper design involves the establishment of firm specifications not only for the individual parts but for all assemblies involving these individual parts.

An important consideration in developing reliability in the end item is the selection of reliable parts. Not only must reliable parts be used but they must be properly applied within the associated circuitry We have recently established an elaborate Vendor Quality Survey system to aid us in obtaining the quality parts needed. Visits are made to plants of new suppliers to inform them of our requirements and surveys are conducted on their operations to evaluate their capabilities to meet these requirements. It took a lot of careful planning to develop this program. One of the big questions revolved around suppliers who handled a few handmade parts on a development basis. Could they produce under rigid requirements of a production program? We have a little story which spotlights this question. We admit it is a bit exaggerated but we think you will appreciate the moral. It's called "The Case of the Resonant Displast."

We hope that the story you have just heard will illustrate the work that goes into the selection of reliable parts. Obviously, considerable additional work in the form of testing, packaging for accessibility and other important considerations go into the basic objective to obtain inherent reliability in the end item. The effectiveness of all these efforts is not fully known, however, until the product is placed in service in the field. Even though an acceptable level of reliability has been achieved, the product may still fail under service conditions if proper support is not available.

In dealing with complex electronic equipment, the Hughes Aircraft Company feels that product support is a fundamental requirement that

demands a well-planned and organized program be developed during the design stage and be followed through equipment obsolescence. If this support program is to be successful, the requirements of the customer must be considered. While his requirements may vary slightly depending on the particular application, they will usually encompass the items shown in Figure 1.

His personnel requirements will include the number in each category and trained in a manner suitable to perform the required operations. The facilities which he will require will depend upon the specific application but will generally include the amount and type of space required, portable and stationary power requirements, testing facilities, calibration and harmonization equipment, and similar items. The equipment requirements will include quantity authorizations, special mock-up or test set-ups, standard and special test equipment and tools, and similar considerations. The spares requirements will normally consist of replacement assemblies and parts (bits and pieces) rather than complete systems. The publications requirements will generally consist of technical handbooks on operation, maintenance, depot overhaul, parts catalogs, and other miscellaneous technical and training information. The service requirements will generally include depot maintenance facilities, either contractor or military operated and fully equipped to handle all maintenance beyond the facilities or capabilities of field personnel to perform. These service requirements will also normally include field engineers or technical representatives in most cases. Some operations also require various special field teams supplied by the manufacturer on operational, maintenance, and supply problems.

The Hughes approach, in support of these customer requirements, is through a separate Company function known as Field Service and Support. These support functions include such items as shown in Figure 2.

Adequate training of operational and maintenance personnel has proven to be a major contributor to high operational performance of all our equipment. Consequently, in planning for all new support programs, we give particularly heavy emphasis to training, to allocation of funds for training, and to necessary facilities for conducting this training. A Factory Training School has been established to cover the training of our own technical support personnel and a nucleus of customer personnel. This school provides two types of courses for customer personnel. One is a short orientation course to familiarize staff level and operating personnel with the over-all equipment. The other is a course to train their technicians in the operation and maintenance of our equipment. In addition to providing the necessary training facilities, the Company also recommends to the customer the type of training, the length of training and the type of personnel required to properly maintain the equipment.

At each airframe company utilizing our equipment, we have a group of engineers and technicians who assist the airframe personnel with the installation and maintenance problems until the aircraft and its associated fire control systems are accepted by the customer. These personnel are provided with necessary spares, test equipment and bench mock-ups to enable them to perform tests and adjustments, repairs and modifications on the equipment. Additional aid is provided the airframe companies in

the form of recommended quantities of common and special test equipment, spares, power requirements, installation facilities and OJT training of their personnel.

When our equipment reaches the field, trained field engineers are made available at squadron level to primarily aid in the transition period between the time new systems are delivered to the squadron and the time the squadron becomes fully operational. In addition to providing technical assistance to the customer, these field engineers also conduct training programs to increase the competence of the military technicians, mechanics, and operational personnel.

A maintenance depot is operated by the Company under contract with the customer. This depot has the capability of overhauling all equipment produced by the Company. As new equipment is developed and placed in production, the depot capability is expanded and established when the first systems are put into use. This is an important asset at all times and especially so when a field operation is first getting started. All units received at the depot are reconditioned, repaired and modified to the latest authorized configuration which results in performance and reliability characteristics equivalent to the most recently delivered equipment.

Spares support coverage is recommended to the customer as a percentage of the end item funds. As the release of engineering data begins, spares specialists start processing this data to prepare the provisioning information. They determine the status and level of reparability, i.e., whether the part is reparable or not and whether the replacement can be made in the field or must be made at the depot. Relative attrition percentage factors on older systems are studied to aid in determining the number of spares required. As engineering changes are incorporated, the support spares are adjusted accordingly. Spare parts are cut back for these parts being deleted or having limited use. New parts are added in the proper ratio to the old and new configurations of the end items.

Special test equipment requirements are determined through liaison with our engineering activities. Proper quantities of each item are recommended to the customer. Quantities approved by the customer are placed in production in sufficient time to allow delivery concurrent with the basic equipment.

Handbooks covering the operation and maintenance of all equipment are essential and are scheduled to be available before or concurrent with the delivery of the equipment. Revisions to these handbooks are issued periodically to keep them abreast with approved modifications and changes in the equipment and specifications. The handbooks cover not only each item of our equipment, but also each item of special test equipment related thereto. In addition, overhaul handbooks covering depot test operations and illustrated parts catalogs are supplied.

From the brief descriptions of the above functions, it should be apparent that some portion of the over-all support program is always in direct contact with the equipment from the time it leaves the plant through its entire useful span; the primary purpose of such support being to provide technical assistance to the customer in any manner he requires. While providing the customer this firsthand assistance, we

are also in a good position to obtain reliable feedback data from the field and depot operations.

Let's first examine this feedback data to see what it contains and then discuss its utilization in improving equipment reliability. The Technical Liaison personnel located at various airframe company installations prepare a combination storeroom requisition and failure report (Figure 3) to replace each part that fails. After serving their initial function as a requisition, these forms are returned to the Company to be used in compiling failure data. These compilations result in a complete and accurate account of all failures encountered during installation of the equipment. These data indicate early equipment failures after only a few hours of operation and are important not only in provisioning of spares for these operations but because they show up the first trouble spots in which we can take corrective action.

All field engineers are provided with "check-off" type field reports (Figure 4) which they are asked to complete for every failure experienced at their respective locations. These reports, in addition to noting the failures, also indicate the circumstances under which the failures occurred. They are also returned to the Company for tabulation (Figure 5). While the completeness of coverage of these reports is difficult to determine, they do present a complete story of the failures reported.

A Modification and Squawk Tag (Figure 6) is made up by Quality Control on all reparable units returned to the maintenance depot. These tags record the detailed repair, replacement and modification work performed on each unit. After the overhaul is completed, the squawk tag is processed by Quality Control (Figure 7). This results in another compilation of data which shows the relative failure rate of all parts. The compilation is arranged in such a manner that all parts contained in each unit are listed separately. If the same part is used more than once in a unit, the number of applications is shown along with the description, reference symbol, part number and failure factor. Such an arrangement makes the failure list readily usable for reliability studies, provisioning, part number reference and other applications.

Numerous other sources of information, both internal and external, are received which also add to our over-all supply of failure data. Such sources include Unsatisfactory Reports, periodic parts consumption reports and similar data.

In addition to the failure data available, a representative supply of failed part exhibits is also available. Since the maintenance depot and various local Technical Liaison activities are close to the engineering activity responsible for developing changes, these activities are usually called upon to supply these exhibits. These exhibits are particularly valuable when failure cause is not readily determinable without an engineering analysis. In the case of vendor supplied items, Quality Control collects and forwards exhibits directly to the manufacturer for study and subsequent improvement of his product.

Now that we have seen the main sources of operational feedback of information and exhibits that are available, let's look into the utilization of this data. Obviously, the objective, if repetitive failures are occurring, is to modify the equipment and to accomplish these modifications as quickly as possible. This means that the changes should be incorporated in production and possibly retrofit into equipment already

delivered. The first consideration is to decide which changes are most important. Normally, failures showing the highest repetitive rate would be considered first. However, even single occurrences where safety is involved take precedence. It will be remembered that three main sources of feedback data are available, namely, Technical Liaison, Field Engineers and Quality Control. The failure rate for any given part may show a wide variation from these various sources (Figure 8). This might lead one to wonder which source is correct. However, the decision is usually rather simple if it is remembered that certain repairs are usually accomplished in the field and that others generally require depot overhaul. A complete picture of failures, then, requires the use of all sources and furthermore, a high failure rate on any one source is usually legitimate and requires action.

Having decided what changes are necessary, Engineering Change Requests go to Engineering describing the nature of the failures, where possible, and indicating the known number of such failures. Engineering analyzes the failures and the results of their analysis usually call for the initiation of Engineering Changes. A discussion of our internal change procedure is outside the scope of this paper other than to say that the net result is the incorporation of the changes in production, retrofit or both.

Another use for the failure data, as I mentioned earlier, is in the provisioning of spares. Obviously, much of this data is not available until considerable time after delivery of the equipment to the field and therefore can only be used on subsequent provisioning. One exception to this is common units used in more than one system where failure data on an older system is reasonably accurate on a new system assuming similar applications are used.

While the direct application of available data on older equipment cannot be used on newer equipment where new parts are used, the data can be revised into part type categories and used with reasonable success. By this I mean that the average failure rate found on 600 volt paper capacitors, for example, in all applications on older equipment can be used to estimate rather accurately the failure rate of this same part type in new equipment. Such part type lists are compiled by Quality Control and are available for initial provisioning purposes where no field experience exists. This type of information can also be used as a guide for design engineers in that they can consider avoiding use of those parts which are known to fail repetitively. This helps to bring about new design configurations of greater reliability expectations.

So far I have discussed the importance of trained personnel, the role they play in assisting the customer in the installation, operation, and maintenance of the equipment, and the process for incorporating modifications to improve the reliability and performance of our equipment. Generally speaking, trained personnel improve equipment performance and engineering changes or modifications improve equipment reliability. However, this is not an entirely clean-cut division of over-all equipment improvement.

Now that our over-all support program has been outlined, the next logical step would be to examine the results obtained. For security and proprietary reasons, the results achieved with Hughes equipment cannot be revealed. Instead, the general method of evaluation will be discussed

followed by a detailed examination of a hypothetical case derived from a general study of military electronic equipment. The first step in evaluating these results is to establish some figures of merit for judging equipment improvement. While there are many ways of partially measuring these improvements, it is believed that maintenance rate, in-commission rate, and mission success rate are among the more important considerations.

The "maintenance rate" is defined as the number of maintenance man-hours required to support each hour of operation. This figure reflects the frequency of failures of the equipment, the amount of time required to locate and replace faulty parts, and, to some extent, the over-all efficiency of the maintenance organization. Under a given set of operating conditions it also provides an index for estimating maintenance man-power requirements.

The "in-commission rate" is defined as the percentage of the total operational time, based on twenty-four hours a day, seven days a week, during which the equipment is entirely ready for operation or is in operation. It is directly related to the maintenance rate in that the more time spent in maintenance, the less time the equipment is entirely ready for operation. However, in-commission rate is significant in its own right in that it provides a basis upon which to estimate the equipment reserve or spares needed to support a given amount of operation.

The "mission success rate" is defined as that percentage of the total number of missions in which there is no interruption due to equipment failure. This figure of merit is more closely dependent upon the reliability of the parts included in the equipment and on the design of the equipment than are either of the other two previously defined rates. The mission success rate, therefore, is a good measure of the "inherent reliability" of the equipment and can be used to determine, on a statistical basis, how many systems must be used to be reasonably sure that the mission will be successfully completed.

The information received from various field organizations is frequently misleading due to differences of operation, differences of compiling the data and the human factor. The latter can be extremely misleading in that maintenance is often performed by personnel not interested in the work and consequently their output is generally below what it could be if good attitude were present. These transient effects plus many others therefore result in considerable spread between performance of the best and the worst field operations.

There are a number of influencing factors common to the three rates which include the experience and training of the operational personnel, the diligence with which training is pursued, the number of trained maintenance personnel, the speed with which the efficiency of the maintenance personnel improves and the design of the equipment itself. An important variable factor is the benefit of experience gained on earlier systems by field organizations which transitioned from older systems to the new systems.

Now as a generalized example, let us take a hypothetical case and illustrate by average curves the progress which might be expected on a complex electronic system. The time base in each case begins at a point when a field operation first becomes fully equipped with its initial complement of equipment.

The "maintenance rate" curve (Figure 9) has an initial downward slope. This slope is caused by a number of factors. Some of the maintenance personnel, although properly trained, may lack practical experience in rapidly locating and replacing faulty parts. Maintenance personnel with little or no training on the equipment require detailed guidance in their operations. A considerable amount of time may also be lost in obtaining parts through supply. During this period of operation, therefore, major quantities of replacement components are desirable which require only harmonization with the remainder of the system to put them into operation. If additional spares are not available, then additional maintenance manpower is required since the total available maintenance time is a constant. In these early phases, the amount of maintenance is not directly proportional to the operational time and cannot be properly evaluated in relation to operational time until the latter is reasonably stable. Although the maintenance rate may start on a relatively high figure, major improvement should be effected over a short period of time. A decrease of fifty per cent or more should be attainable in the early phases of operation.

The "in-commission rate" curve (Figure 10) rises steadily during the initial phases of operation. As previously stated, this curve is directly related to the maintenance rate in that the more time spent in maintenance, the less time the equipment is entirely ready for operation. During this phase of operation, therefore, a higher percentage of equipment reserves are needed to support a given amount of operation. Again, the leveling off spot in the curve should be achieved in a relatively short time. Generally the in-commission rate should increase by twenty-five per cent or better.

The "mission success rate" curve (Figure 11) should rise rapidly in the initial phases of operation. This curve reflects the increasing efficiency of the operational personnel. As time goes on, inexperienced operators develop greater confidence and ability in the use of the equipment. Experienced operators transitioning from other types of equipment require time to learn different techniques required on the new equipment. Improvements of approximately twenty per cent in this rate should be possible.

The greatest improvement will generally be found in the maintenance rate, since it includes the training of personnel, morale, and the availability of supply and test equipment. Of these, training is usually the outstanding contributor. The in-commission rate also indicates good improvement but since this is directly related to the maintenance rate, improving one will obviously improve the other. Since it is generally a simpler task to train operational personnel than it is to train maintenance personnel, it would be expected that the improvement in mission success rate would be less.

Many problems will be encountered in trying to get all facets of a support operation to function smoothly and on schedule, especially in the early phases of a new program. Each operation should be designed to assist the customer in some aspect of his over-all mission responsibility. This assistance should include helping him to obtain the necessary trained personnel, special test equipment and spares concurrently with the equipment and properly distributed. Through feedback information, it is possible to incorporate modifications at the earliest feasible point in production and to accomplish retrofit with the least

possible delay. This increases equipment reliability and performance beyond the latest "State of the Art" reflected in the original manufactured article.

I have purposely left until last a very basic consideration which is essential in any successful operation. This consideration is quality workmanship. If this is neglected anywhere along the line from initial manufacture to ultimate obsolescence, reliability will be seriously affected. It, therefore, includes all field and depot maintenance performed on the equipment as well as careful handling techniques. We are continually trying to improve these techniques, not only within the Company but also through customer personnel training. I have a film we developed called, "The Priceless Component" which illustrates the importance of good workmanship. Since all of us are anxious to get the best out of our employees, I thought you might be interested in seeing it.

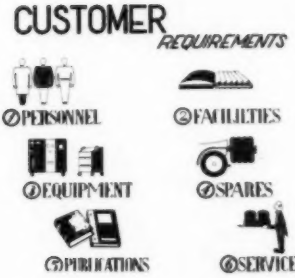


Figure 1

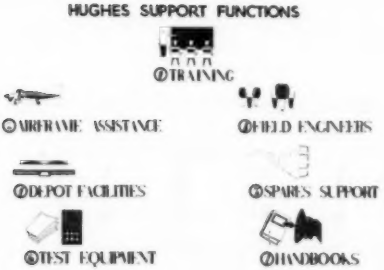


Figure 2

STOREROOM REQUISITION AND ELECTRONICS FAILURE REPORT

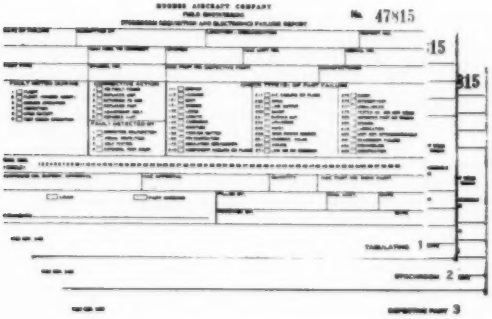


Figure 3

ELECTRONICS FAILURE REPORT

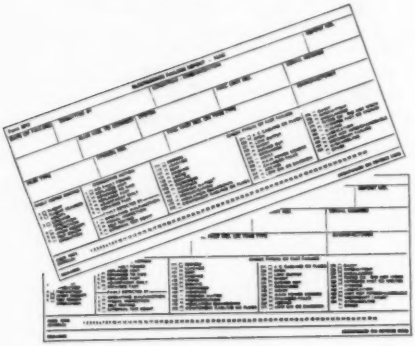


Figure 4

FEEDBACK DATA FROM THE FIELD

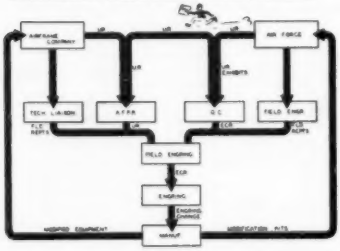


Figure 5

MOD & SQUAWK TAG

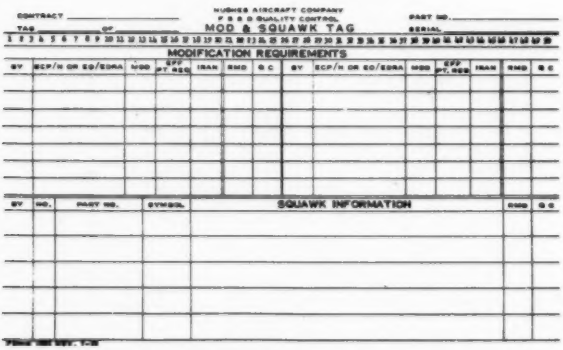


Figure 6

FEEDBACK DATA FROM THE DEPOT

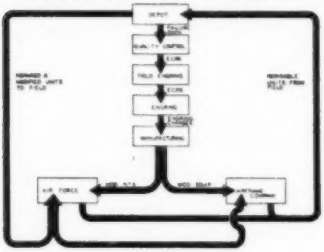


Figure 7

DIFFERENCE IN FIELD & DEPOT DATA

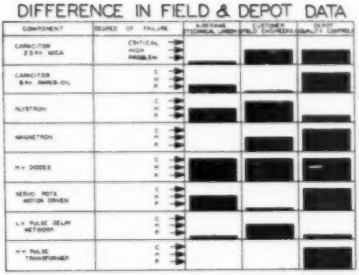


Figure 8

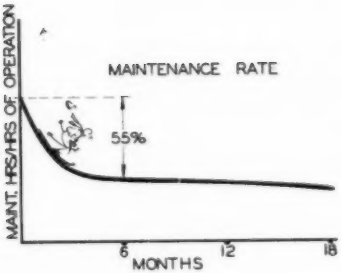


Figure 9

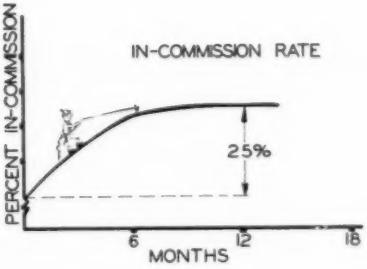


Figure 10

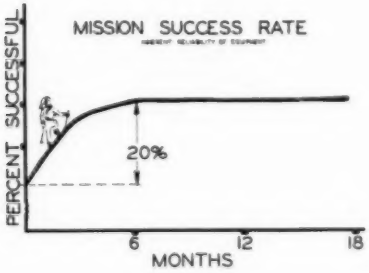


Figure 11

A QUALITY INCENTIVE FOR OPEN HEARTH MELTERS

J. Robert Behrman
Alan Wood Steel Company

A very interesting definition of statistical quality control has been developed by Dr. J. M. Juran, Consulting Management Engineer. He states that control is the totality of all the means by which we establist and achieve a standard. Thus from production control we get a schedule and from expense control we get a budget. Similarly, quality control is the totality of all the means by which we establish and achieve a specification. Statistical quality control is that part of quality control which utilizes the tools of statistics. All too often the emphasis is on the statistics--we have a new cure, let's find some diseases. Actually, we should start with the problem, recognize it, define it, and then find the correct tools to solve it.

The problem, which was recognized by the management of Alan Wood Steel Company in 1950 and 1951, was the need to increase the production of ingots capable of meeting the more rigid specifications of Strip Mill applications. The problem was broken down into the following essential parts:

1. A high percentage of cold bottom cast heats with resulting pouring difficulties.

2. Excessive product loss because of skulls. In 1951, the average skull rate was 1145 lb. per top cast heat with skulls of 5000 lb. and over accounting for 70% of this loss.

3. A high percentage of heats was being diverted causing schedule problems.

4. Poor surface quality of semi-finished and finished product.

5. Production rate was unsatisfactory and had to be increased along with the required improvement in quality.

Fundamentally, the solution of the problem hinged on the necessity for driving furnaces with inadequate checker capacity to obtain the tapping temperatures required for successful bottom casting and good rimming, low carbon top cast. It appeared that some sort of incentive for melters could be the answer. For a good many years, monthly reports showing the relative performance of the various melters had been put out by the Metallurgical Department. However, it was apparent that this was not achieving the desired results. Consequently, management conceived the idea of incorporating a quality bonus with the tonnage bonus. It became the responsibility of the Industrial Engineering, Open Hearth and Metallurgical Departments to develop the method for determining the quality bonus.

The plan as adopted in November 1951, consisted of three parts. Melters were to be ranked according to their composite ratings determined from (a) the percentage of total heats tapped relative to turns worked,

(b) per cent missed chemistry, and (c) per cent cold heats. The top melter each month was to be given a flat bonus. As may be seen from some of the charts which will be shown later, some benefits were derived from this plan. However, there were two disadvantages. Occasionally the rating for heats tapped compensated for quality deficiencies to the extent that a melter won a quality bonus because of increased production. Furthermore, no recognition was given to the melter ranked second even though the narrowest of margins separated him from the first melter.

To correct the disadvantages of the first plan, a revised incentive system was put into effect in February, 1953. The revisions were developed from a statistical analysis of the first five months of 1952 and consisted of three parts which are outlined briefly as follows:

1. Temperature Performance

   a. Top Cast: A skull of 3000 lb. or over was to be charged against the melter. Previously a 5000 lb. limit had been in effect.

   b. Bottom Cast: A bottom cast heat was to be considered cold if there was a ladle skull. Previously, this was based on the pouring of butts. However, it was shown statistically that the most reliable index of the condition of bottom cast pouring was the presence or absence of a skull.

2. Chemistry Performance

   A heat missed for any element over which the melter has control is charged against him. An element is missed when it exceeds a specified deviation from the median of the ordered range. For example, when the median of the ordered carbon range is under .20%, the allowable deviation is ±.02%.

3. Diversions

   Any heat which may be classified as a diverted heat may be charged against a melter. This includes bottom cast heats which do not pour 70% of the set-up as well as heats diverted to other orders for excessive skulls or missed chemistry.

A melter is not penalized for any deviation from a quality standard caused by factors over which he has no control. In each of the above three sections a rating is calculated by dividing the non-penalty heats by the total heats tapped, the three then being averaged to obtain a composite performance rating. The melter is paid a quality bonus proportional to the amount his rating exceeds a reference rating. In this manner, a melter is compensated for his own performance with respect to a set standard. A production factor has been maintained in that a melter must tap at least 10% of the total heats for the month to be eligible and at least 20% of the total heats to receive the full bonus his rating entitles him to.

The improvement in open hearth performance which may be attributed

to the melters' quality incentive is impressive. The per cent of cold bottom cast heats dropped from 19.4% in 1951, to 17.7% in 1952, and to 11.8% in 1953. The weight of skull per top cast heat decreased from 1145 lb. in 1951, to 940 lb. in 1952, and to 690 lb. in 1953. Diversions have been reduced materially. Improvements in these and other variables are shown graphically in the accompanying charts.

Figure 1 shows a three-month moving average of skull weight in pounds per top cast heat. It will be noted that there is a drop of about 200 lb. per heat between the first and second incentive plans, followed by a drop of 500 lb. per heat before achieving 100% coverage with immersion thermocouples. With the use of a reliable bath temperature measuring device, the skull rate decreased further to a level of less than 100 lb. per heat for the last quarter of 1954. It will be noted throughout these charts that open hearth operations were very seriously affected by the hot weather during the summer of 1955. For example, the skull rate increased to about 320 lb. per heat during that period.

Improved sulfur control is charted in Figure 2, showing a decreasing trend in the per cent of heats over the ordered maximum in ladle sulfur.

Figure 3 shows a similar moving average of diverted heats for which melters were penalized. Changing standards for diverting heats made it impossible to carry this chart back into 1951. However, the sharp downward trend is apparent especially after the revised incentive plan was put into effect.

Of particular interest is Figure 4 in which two curves are shown comparing performance ratings of 1952 and 1955. The probability of a melter's getting a rating of .950 or better was only 3% in 1952. In 1955, this had increased to 73%. Conversely, a rating under .930 had an 82% probability in 1952, but only 2% in 1955.

A control chart of melters' quality performance is shown in Figure 5. Points are plotted for each month representing the average and range of the ratings for the four principal melters. Limits are calculated on an annual basis. The steady improvement for the first three years is apparent in the chart of averages. It will be noted that the average rating dropped slightly in 1955. However, this may be attributed to the effect of the extremely hot weather in July where the rating is well below the lower control limit. If this month is excluded, the annual average is comparable to that for 1954 notwithstanding an increase of 93% in production. It is also interesting to note that the average range was considerably lower in 1955 than in any of the preceding three years.

The best indication of the effect of the improvement in open hearth performance on steel quality may be found in the reduced per cent of defective slabs in the plate mill. Plates are inspected on a lay-out table. If a defect makes it impossible to shear the full pattern, it is recorded as one defective slab. Defects are classified as "steel" or "mill". Through 1954, the greater portion of the steel for the Plate Mill was poured bottom-cast, and, prior to 1953, at least a third of these heats were poured into slab molds to be rolled directly into plate. Consequently, there was a high degree of correlation between pouring condition and the per cent of scabby plates. Table I shows how the per cent of steel defects in plates decreased as temperature control

improved in the open hearth.

Table I. Effect of Cold Bottom-Cast on Plate Mill Defects

	Regular Bottom-Cast		Slab Heats	
Year	% Cold	% Steel Defects	% Cold	% Steel Defects
1951	16.7	4.9	27.0	8.6
1952	15.2	4.4	23.1	8.4
1953	10.7	4.0	18.6	6.0
1954	6.6	2.8	2.3	6.9 *

* Includes inventory carry-over which was rolled completely prior to modernization of plate mill.

The improvements in quality which have been reported in this paper have not been achieved at the expense of production. On the contrary, the total output of ingots in 1955 exceeded that of 1951 by almost 7%. By the end of 1955, the tons per hour rate exceeded the average for 1951 by almost 10%.

In conclusion, it should be pointed out that a quality incentive will not do the job by itself. There must be a follow-through by management. Every other week the Open Hearth superintendent holds a meeting of melters and other foremen in his department. At this meeting performance charts are exhibited, and melters and pit foremen are kept advised of quality trends in semi-finished and finished product. The combination of a concerted effort on the part of melters and supervision with the added incentive of a quality bonus has resulted in a marked improvement in open hearth performance at Alan Wood Steel Company.

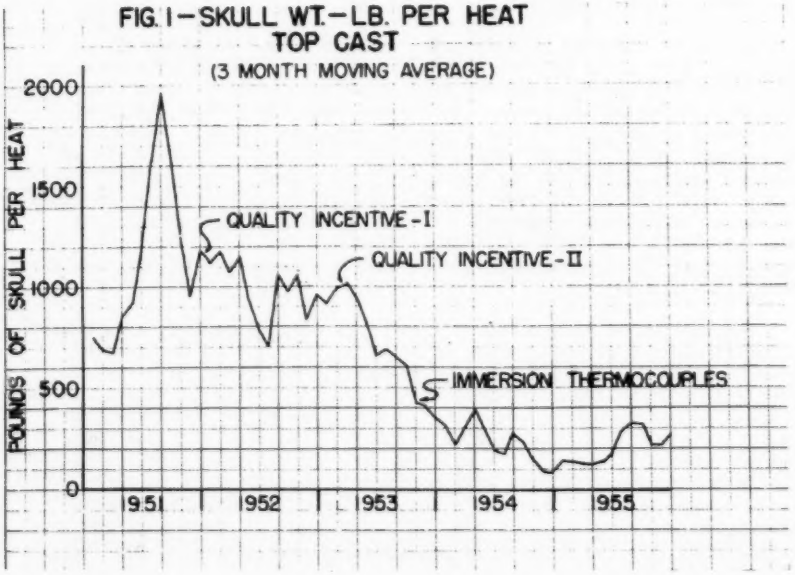


FIG.2-LADLE SULFUR
% OVER ORDERED MAXIMUM
(3 MONTH MOVING AVERAGE)

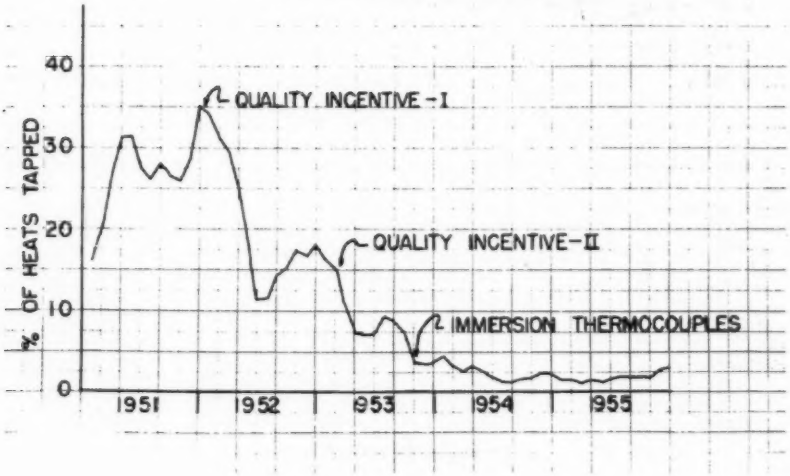
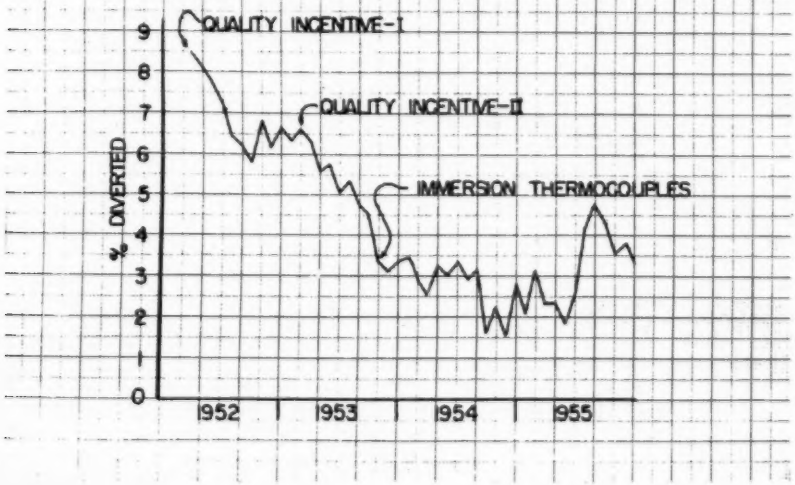


FIG.3-DIVERTED HEATS
(3 MONTH MOVING AVERAGE)



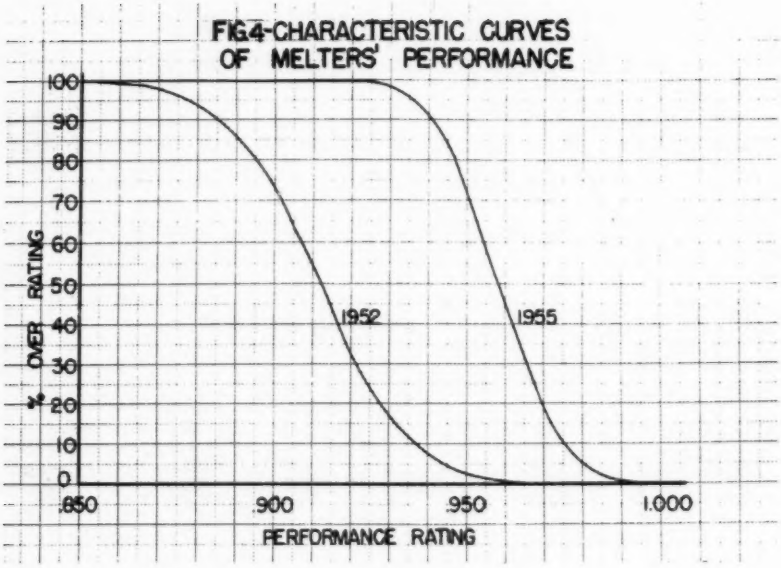
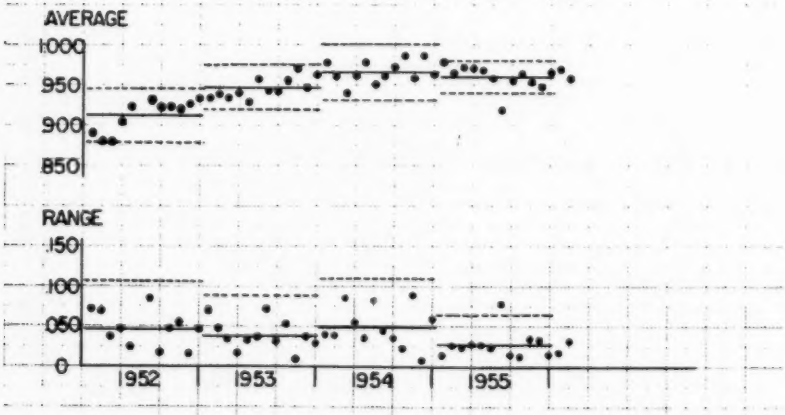


FIG. 5-CONTROL CHART OF MELTERS' PERFORMANCE
MONTHLY QUALITY RATINGS — FOUR PRINCIPAL MELTERS



SEARCHING FOR ASSIGNABLE CAUSES IN AN INTEGRATED STEEL PLANT

James A. Curry
Kaiser Steel Corporation

The basic approach to the control of quality in an integrated metals manufacturing process is no different than in any other manufacturing enterprise which starts out with a variety of raw materials and processes them into finished products. If the approach is taken that the finished product of one phase of the operation, such as a cast ingot from the Open Hearth, is the raw material for a succeeding operation, a blooming or slabbing mill, then the three basic steps of specification, processing and inspection apply, not only in the finished product shipped to the customer; but equally as well to each intermediate production step.

Statistical quality control has also logically been broken down into these same three broad categories, i.e., control of specification; control of production; and inspection control. These three phases of quality control do not however, assume the same magnitude of importance in all industry. In steel, for instance, the statistical approach to specification and inspection is just now beginning to receive some attention; because the concept of statistical determination of tolerances and specifications and the concept of acceptance sampling of finished products for dimensional, visual, and physical defects has not been generally accepted by either steel manufacturers or their customers.

The major difference then in routine quality control in an integrated metals plant as compared to a small parts manufacturer, is that in the metals industry the major emphasis is more likely to be placed on process control, while at a small parts manufacturer it is more likely to be placed on inspection sampling and/or statistical determination of tolerances.

The function of statistical quality control, as practiced at Kaiser Steel Corporation is divided into these two major fields:

1. Process control.

2. Process and product improvement.

To maintain process control, once it is achieved, is usually a routine procedure. The fundamental statistical quality control techniques, operated by statistical clerical personnel is usually adequate for this purpose. All that is required is the routine and systematic measurement of those factors which have been found to affect the process.

However, in the experience of the writer, we have yet to find a process in the steel industry that was "in control" in the statistical sense of that term. In the integrated manufacture of metals, elimination of assignable causes is not usually a simple matter of machine adjustment or changing a tool. It often involves a complex variety of interrelated variables. It is in this area of determination and evaluation of assignable causes, that the technique of "search" has its largest field.

It is estimated that fully 90 percent of the time and effort of our Statistical Control and Yield function is devoted to this search for

causes and only 10 percent in the routine of process control. The methods employed and the organizational set up for performing this function assume a great deal of importance.

With this in mind, it might be valuable to explain in some detail how Kaiser Steel Corporation is set up to conduct this search for assignable causes and for process and product improvement instead of developing in recipe form any of the many statistical methods which are used. By first explaining the organizational set up, then following through the steps of one particular search, it should be possible to show how the responsibilities for the various phases are assigned, how the data is collected and how the final results are reported and acted upon. In following through one specific example, it will be possible to generalize from the particular, to indicate how most problems of search are conducted.

The Statistical Control and Yield Section is set up as one of the divisions of the Industrial Engineering Department. The function is staffed by a supervisor, a senior statistical engineer, junior grades of engineers and clerical personnel.

The Statistical Control and Yield Section is a staff function and has no functional connection with either line, metallurgical or inspection departments. The engineering personnel of the section are selected from persons having industrial, mechanical, electrical or metallurgical engineering backgrounds, rather than by choosing men who have only a mathematical statistical training. This choice is for a definite, and it is believed, valid reason. Experience has shown that after assignable causes are tracked down, the problems of elimination or correction remain to be solved. This often requires methods studies, cost analysis, mechanical or electrical changes, or metallurgical considerations. Having this variety of experience, in addition to the requisite statistical training, enables the group to function more effectively than if dependence was had on a purely statistical, or statistical-metallurgical approach.

It is the general rule that in each processing area in which the Statistical Control and Yield Section operates, a quality and yield committee has been set up. This committee is composed of three members: the superintendent of the operation, the division metallurgist responsible for that particular operation, and the supervisor, statistical controls and yields. The various operating superintendents act as chairmen of their respective committees, and the supervisor, Statistical Controls, acts as the secretary and issues reports of findings, progress and recommendations.

The function of these committees is to decide on areas in which investigations will be made, to define the purpose and objectives of the investigation, to coordinate the activities of various departments concerned, and to submit recommendations to management.

In the planning of an experiment or investigation, having this committee composed of operating, metallurgical and statistical control and yield personnel, is of inestimable value. Each committee member assumes those responsibilities which logically fall into his area. Problems concerned with operations are handled by the mill superintendent. Problems of data collection, inspection, observation, etc., are handled by the metallurgical member. The design of the tests and experiments

connected with the investigation, the analysis of the results, analysis of recommended changes in equipment or processes, the design of control methods, etc., are the responsibility of the Statistical Control and Yield group. In those cases where additional personnel is required to conduct tests or experiments, each committee member is responsible for furnishing personnel to carry out his assigned responsibilities.

There is another advantage to this "committee" type of effort, which although intangible, is nevertheless very real. That is the advantage of having or developing a sense of participation and involvement in methods, quality control and yield improvement. Too many times the quality control engineer is regarded by operating personnel as an unnecessary evil, one who has nothing in common with operating objectives and aims. However, with this committee approach, this attitude and its consequent obstructions can be minimized.

Any type of organizational set up may look fine in theory. The real test is, "How does it operate in practice?" The following example of a problem of search for causes will illustrate how the committee approach operated on one specific problem.

In the manufacture of steel plate, the irregular sides and ends produced by the rolling operation must be trimmed off to produce the exact plate dimensions ordered by the customer. In steel terminology, radiagraph plate is that plate which is cut to pattern by a precision flame cutting machine because the plate is too thick to shear mechanically. At Kaiser Steel Corporation, plate over one inch thick is processed in this manner. The slabs from which the plate is rolled are from 10 to 12 inches thick and 36 to 48 inches wide. The heated slabs are first passed broadside back and forth through a reversing mill to attain the required width; then they are rotated 90 degrees and rolled to the required gauge, thereby also attaining the necessary elongation.

A few months ago our plate mill developed an alarming increase in reject rate on these heavy plates. On inspection of the rolled plate it was found that on approximately 50 percent of the pieces an elongated sliver was present on the bottom side in one or more of the four corners of the plate. (Figure 1) Sometimes these slivers would be cut off with the end and side scrap but many times the plate would not make the ordered pattern and would have to be cut down to a smaller size to eliminate these slivers. This not only resulted in loss of yield, but produced an inventory of heavy plates for which we had no immediate order, and, often caused a fall down on promised delivery dates.

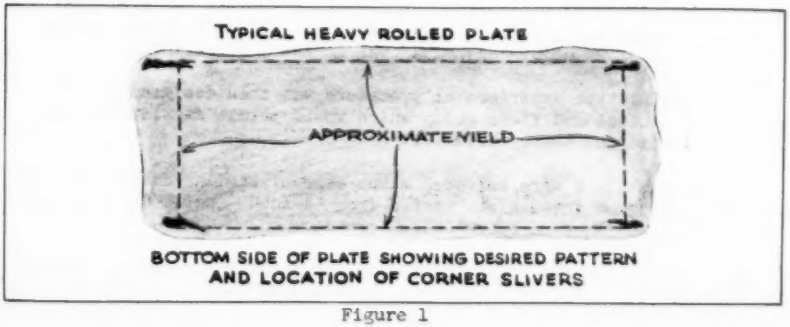

TYPICAL HEAVY ROLLED PLATE
APPROXIMATE YIELD
BOTTOM SIDE OF PLATE SHOWING DESIRED PATTERN
AND LOCATION OF CORNER SLIVERS

Figure 1

At the request of the Assistant General Superintendent in charge of Rolling Mills, the Quality Control and Yield Committee for the Plate Mill undertook the search for causes of these corner defects.

At a meeting of the committee it was decided that the Quality Control and Yield group would interview everyone from the assistant general superintendent to the sweeper who had any knowledge of rolling of heavy plates, for ideas as to possible causes. We had only three facts to go on at that time. These facts were:

1. The slivers always occurred on the bottom side;

2. They were invariably located in the corners;

3. The slivers were all parallel to the long dimension of the plate and were all "hinged" nearest the ends of the plate.

As a result of the interviews, a comprehensive list of possible causes was developed. This list of causes was evaluated by the committee and ranked in order of the committee's judgment of probability. These causes were associated with one or more of the following variables:

1. Furnaces: Three reheating furnaces are used simultaneously to heat the slabs from which these plates are rolled. Furnaces #1 and 2 each have 65 tons per hour rated capacity and #3 furnace has a rated capacity of 125 tons per hour. The charge and discharge ratio by furnaces was 1 - 1 - 2.

2. Scarfing practice: Scarfing is the process of surface burning to remove surface defects on the slabs. It was thought that protruding corners sometimes left by the scarfing operation could be the cause.

3. Slabbing mill rolling: This mill had recently been converted from a 36" mill to a 46" mill. It was still in the "shakedown" period.

4. Injuries to the slab associated with the operation of the furnace run-out apron, roller conveyors or mechanical handling while the slab was hot.

5. Rolling Practice: High on the list of probable causes was the "draft" pattern, i.e., the amount of reduction taken in succeeding passes through the mill. It was believed that too heavy initial draft might cause the rolls to nibble at the entering edge, causing a tear in the slab surface.

A factorial type experimental procedure was then designed by the Statistical Control and Yield group which would permit statistical significance testing of these variables.

Thirty-six slabs were selected which were of similar dimensions. The finished plate from these slabs varied from 54 to 90 inches in width and from 1 1/2 to 4 inches in thickness.

Half of the slabs were re-scarfed to round off the corners. Half of the slabs were turned over so that the bottom side from the slabbing mill would be the top side through the plate mill. The slabs were then

arranged and charged in a definite sequence. One-fourth of the slabs were charged into each of furnaces #1 and 2 and half were charged into furnace #3. The draft was varied in a manner designed to give fractional replicates of a factorial design. Half of the slabs were rolled by the regular rolling practice and half were rolled using one-half the normal draft with consequently twice as many passes through the mill as normal.

To help visualize the sequence of operations, a plan view of the location of the equipment, furnaces, conveyor, mill, turnaround, etc., referred to in this problem is shown in Figure 2.

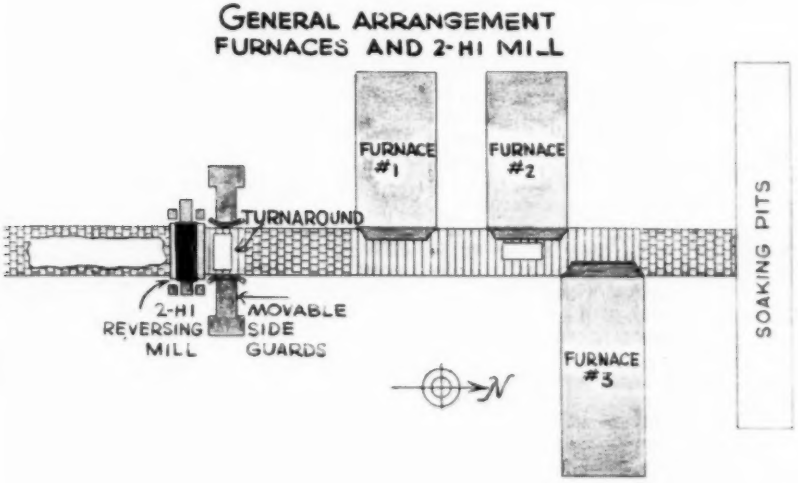


Figure 2

Observers and recorders were assigned to follow each step of the process, and values and observations were recorded. The whole test was completed without delay to operations.

After the rolled plates had cooled, they were inspected by the committee. The corner defects were located, measured and identified to slab number.

As a result of the analysis of the data obtained, the following tentative conclusions were drawn:

1. The slabbing mill was probably not a contributing factor. Corner defects on slabs which were charged upside down were still on the bottom and showed no significant difference in occurrence from slabs charged in the regular way.

2. There was no significant difference in occurrence of corner defects between the front and back end of the plate

3. There was no significant difference in results as obtained by drafting pattern. Half draft slabs had just as high a defect rate as full draft slabs.

4. There was no difference by plate width or thickness.

However, we did get some significant differences in other variables: for instance we found that:

1. Number 3 furnace produced more than its share of defective corners.

2. There was a significant difference in the occurrence of defects between the east and west sides of the plate as it issued from the mill, defects occurring on the east side in significantly greater number than the west side. This association permitted us to draw another conclusion; that the defects were probably not caused by mechanical injury on the furnace discharge aprons. Since furnaces #1 and 2 are located on the west side and furnace #3 on the east side of the conveyor feeding slabs to the mill; the concentration of defects was on the leading edge of slabs discharged from furnaces 1 and 2 and on the trailing edge of slabs discharged from furnace #3.

3. Rounding off of slab corners showed a probable significant decrease in defects, although this association was not so highly significant. It was believed that these sharp corners could be a contributing factor but was probably not the major cause.

4. By measurements taken of length and width of the slivers, a direct correlation was found between the width of the sliver and the width of the finished plate; and a good degree of correlation enabled us to draw one other conclusion, that was, that the injury happened early in the rolling process and was widened by broadsiding the slab to get the required plate width and was elongated in subsequent rolling operations to reduce plate to the required length and thickness. In fact the time of injury was narrowed even further, in that it could only have occurred on an early broadside pass, otherwise sliver widths would have been the same and varied only in length.

The nature of the injury was such that since the hinge of the sliver was always toward the end, it could only happen on the leading edge while the slab was moving forward. Otherwise the hinge of the sliver would have been on the inner end and the sliver would have been elongated toward the end of the plate. Reasoning from this fact to the significant difference between the east and west sides of the mill, it was determined that the slab was injured, not only on a broadside pass, but on the pass entering the mill from the south side. The reason then for the significant difference between east and west side injuries became apparent, in that it is the usual practice of the table operator to rotate the slab in a clockwise direction, the slab being rotated 90 degrees clockwise to start the broadsiding passes, and again 90 degrees clockwise after broadsiding before starting the final rolling to length and gauge.

This would place the east side of the plate as the north or leading edge during broadsiding while the slab was moving from south to north.

It was mentioned above that it was the usual practice to rotate the slab in a clockwise direction, but this was not always the case. Sometimes the operator would reverse the direction and rotate the slab 90 degrees clockwise and the second time 90 degrees counter-clockwise. This then accounted for the slivers sometimes occurring on the west side of the plate.

As a result of the information gained from this experimental rolling a theory was evolved as to the cause which fit all the known facts. This theory was: that because of differential heating, top and bottom, of heavy slabs, they tend to roll convex in the broadside passes. The observed shape, from end view, during broadsiding was as indicated in Figure 3.

As in most steel mill furnaces, the top of the slab receives most of the heat. Being hotter, unless adequate soaking time is allowed, the steel is more plastic and freer flowing on top which causes the convex shape as illustrated in Figure 3.

When the slab is ejected from the rolls it tends to come out cornerwise, i.e., not at right angles to the roller table.

On the south side of the mill the slab is frequently returned to the rolls with either the northwest or northeast corner leading. This leading corner, bearing the entire weight of the slab which would normally be supported by the entire leading edge if the slab was lined up with the roll axis, either hits a stripper roll or a sharp slot edge in the stripper plate, causing a gouge, which in turn is rolled into a sliver. This damage occurs only on the south side of the mill because the slab is aligned on the north side of the mill by use of the movable side guards. There are no movable side guards on the south side of the mill.

By deduction this theory placed the blame on differential heating because of inadequate furnace soaking time for heavy slabs. To test this theory, nine slabs were heated in the ingot soaking pits to assure uniform heating. The slabs were rolled in the normal manner and on inspection of the rolled plates, no sliver defects were found.

However, searching out the assignable causes is only half the problem. After the cause has been determined, the problem still remains as to what to do about it and/or how to correct it. In the problem outlined above, four possibilities were listed without effort to evaluate the practicability of the various possibilities. There were:

1. A change in charging pattern of heavy slabs. Differential heating is a function of soaking time. The hearth length on furnace #3 is only 10 inches longer than on furnaces #1 and 2, even though #3 has double the rated capacity of furnaces 1 and 2. Consequently, the soaking time in #3 furnace is approximately one-half as long as for furnaces #1 and 2, when the charging pattern is such as produces a 1 - 1 - 2 ratio. If more bottom heat was applied in the heating zone of #3 and a charging pattern was adopted which would discharge slabs equally from all three furnaces, better soaking would result in #3 furnace.

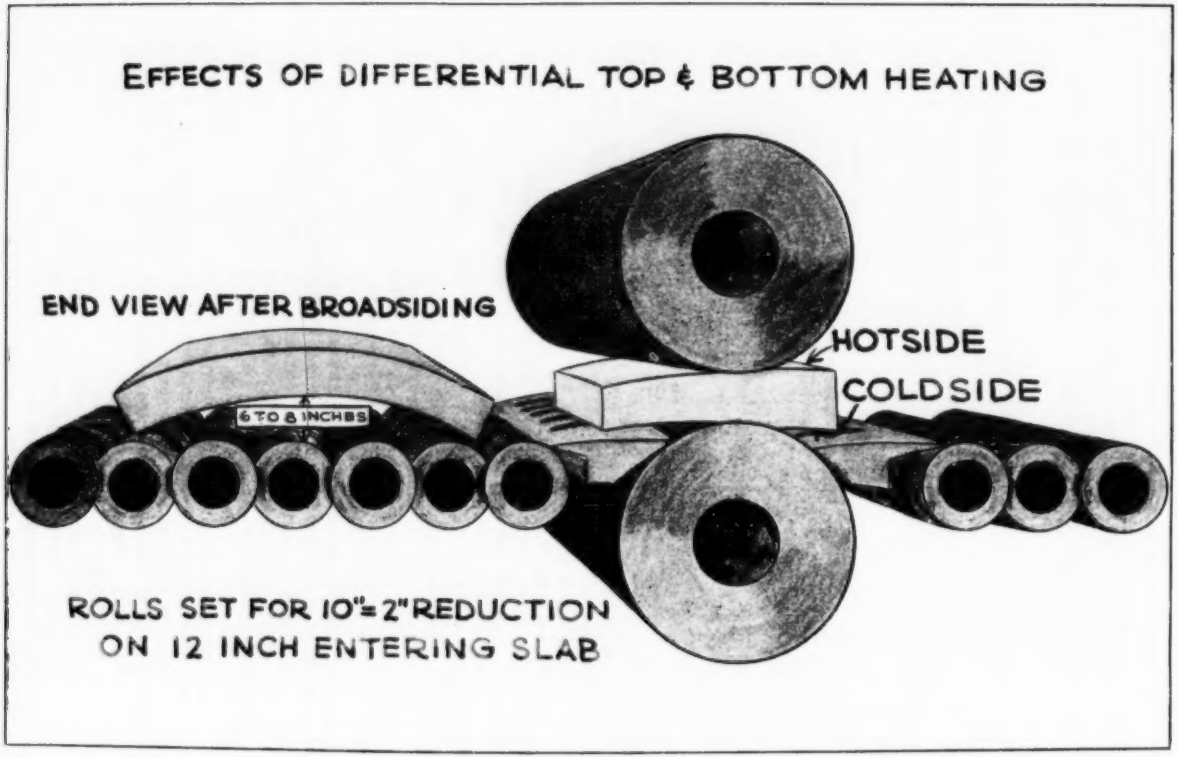

EFFECTS OF DIFFERENTIAL TOP & BOTTOM HEATING
END VIEW AFTER BROADSIDING
HOTSIDE
COLDSIDE
6 TO 8 INCHES
ROLLS SET FOR 10"=2" REDUCTION
ON 12 INCH ENTERING SLAB

Figure 3

2. Install side guards on the south side of the mill to square up the slabs before reverse rolling.

3. Redesign the stripper table on the south side of the mill to eliminate sharp edges, thus eliminating corner gouging.

4. Heat heavy slabs in the ingot soaking pits. If practical this could be done either in whole or in part. To allow sufficient soaking time in the furnaces, just enough slabs could be heated in the pits so as not to reduce rolling rate on the mill.

Here again the committee approach as well as the diversity of experience and training of the Statistical Control and Yield Section proved its worth. The relative merits of each of the four possibilities could be evaluated from an operating, engineering, metallurgical and cost standpoint. It was found that the best overall solution was to change the charging pattern of heavy slabs among furnaces to a 1 - 1 - 1 ratio instead of the 1 - 1 - 2 ratio which had been used. This was done and the problem disappeared.

Thus the search for the cause and the best solution were successfully concluded. In this one problem several statistical techniques were used. Factorial design allowed us to test for a number of possible causes simultaneously, chi square and the 't' test were used in addition to variance analysis to test for significant differences. Correlation analysis led us to the conclusion that the defects were caused in the broadsiding passes. It is probable that this problem could not have been solved as efficiently by using any single statistical technique.

Figure 3

Experience points out that in the search for assignable causes, the statistical detective should not confine his search to the use of a limited number of pet methods, but, by having a comprehensive knowledge of proven methods, he can, depending on the particular problem, choose and select methods of analysis of data which will give the required answers most efficiently. Of equal importance is an organizational set up which enables the search for causes to proceed with the greatest amount of cooperation and participation possible.

THE USE OF STATISTICAL QUALITY CONTROL IN THE MANUFACTURE OF ELECTRICAL EQUIPMENT FOR USE IN AUTOMOBILES

Fred D. Reardon
The Electric Auto-Lite Company, Spark Plug Division

It is not my intention here to go into a long discourse on the use of statistics in the control of quality in manufacturing, but rather show the practical use we make of control charts.

On the control of quality and scrap in the manufacture of Auto-Lite Spark Plugs, we use a variety of charts, designed by us specifically for the material or job with which we are working. This, I believe, is necessary. Sampling is done in accordance with Military Standard 105-A. In some cases we exceed the required amounts, although not excessively. This gives only further assurance of quality.

The materials used in the manufacture of spark plugs are platinum, silver, nickel, steel, and many ceramic materials, the latter for the porcelain, kilns and kiln furniture.

Regarding the ceramic material: This is received from the mines in different forms; namely, air floated, dry and semi-dry. The batches are started through the plant in a liquid state, approximately 50% moisture, then reduced to a putty consistency for further processing. This material of putty consistency is then processed through what is known in the ceramic industry as a "pug mill", emitting in the form of a cylindrical blank with a hole through the center, for a spark plug insulator.

The next step is to reduce the moisture content of the blank to less than two tenths of one percent, which leaves a product of chalk consistency. The blank then passes through nine operations before firing. You can visualize the amount of scrap produced in working with chalk on machining operations. Furthermore, we have a 40% shrinkage, by volume, which demands close controls. As an example, in tapping we cut 21 threads per inch and after firing we have 22 threads per inch.

When installing the Quality Control program we concentrated more on how to reduce the scrap rather than on the quality of the semi-finished product leaving the department. I do not mean that we disregarded quality entirely, for we set up a chart by the hour on the outgoing material. The quality was high and has remained so through the four years this system has been operating.

A study was started on various machines and a forecast drawn up on how much scrap could be expected per hour from each of the operations. Some changes were made in sizes and tolerances, worked out between the Engineering Department, Ceramic Division, and the Quality Department. By this group study it was found that many of the tolerances noted on the blue prints were not accurately calculated, but as in so many cases, improperly selected. This study showed that we were passing parts that did not conform to prints and as trouble did not ensue in the following operations, it was decided to change the prints accordingly. Under the former dimensions, roaming inspectors checking the machines could always find variations. The machine would be stopped, arguments followed, resulting in lost time and production.

This now has been eliminated. We have a higher quality product and the charts proved our former practice to be erroneous.

To correct this, charts (daily and weekly) especially designed by the Quality Control Department, for listing hours and number of pieces of scrap, were placed on a blue board and mounted on each machine. A movable green ball and red hand were also attached to the board. All machines were equipped too with a red scrap pan. The department was closed down, all operators assembled and our intentions thoroughly explained to them. Previously we had given the foremen and union committee the same explanation.

The Inspectors' duties were changed from checking sizes to gathering scrap. Each hour they visit the machine, count the scrap and record same on the chart. The green ball is raised if the scrap is under expectations; if over, the red hand is raised. This indication shuts down the operation for the job setter. The machine operator also raises the red hand if trouble occurs.

The success of this plan is proven by the following figures:

The number of Inspectors have been reduced by six per shift;

from 1952 to 1953 (the year after this method was started) the scrap loss was reduced 20%;

1953 to 1954, a reduction of another 50%;

1954 to 1955, another 20%.

The quality of the ware naturally has also increased.

At the vitrifying kilns, the practice of making a great number of destructive tests, not in any pattern and at great loss of product and high cost, has been altered to a controlled sampling procedure. Samples are taken by the kiln operators and placed in blue pans (a color reserved for all Quality Control equipment). The pans are then gathered by the Quality Control operator. One half of the sample is for the purpose of measuring; the other half for the Ceramist. Upon receiving the approval of both, the ware then is released for further processing. Rejections and loss of ware and cost have been greatly reduced.

There is one assembly operation on the insulator where six parts are driven together on a hydraulic press. It was necessary (according to the blue print) to hold a dimension from the top of the assembly to the top of one of the parts inside. This became so serious that different lengths were made on three of the parts. Electric depth gage machines were designed and purchased. These operated on the principle of the pin-ball machine, a light radiating at a given depth. All production was run over this, grouped and assembled with parts of the proper size. This was our first real use of charts. After a study by Quality Control it was pointed out that the parts were all following a certain pattern, and that with a change in one of the dimensions the desired results could be obtained. Today the parts are all of uniform size and a sample is taken once an hour.

This same general program is followed through the rest of the plant with some variations. The machines in the final assembly department are all equipped in the same manner as previously explained, with the scrap pan and control charts, excepting all material placed in the red pans in this department is not scrap. Much of it may be repaired. To provide for this we have installed on the first machine of the group, a yellow pan. The material that the Quality Control operator decides can be repaired is placed in this pan. The production repair operator repairs, if possible, the product, placing same on the conveyor. In the event the part is destroyed, it is given to a Quality Control operator who makes a record for the scrap report and places the part in scrap.

Again, in another department we may establish a Quality Control operator at a table, and the production repair people gather the defectives, make possible repairs, and deliver the scrap to the Quality Control operator at the table for record and disposal.

The Automatic Screw Machine Department presented quite another problem. There are some sixty machines, each producing a part every eight seconds. There are also twelve machines making small parts. We had six roaming inspectors on the floor, all with designated areas. All production operators were on piece work. An operator would not halt work unless ordered to do so by the inspector. For many reasons the inspector was always on the machine running O.K. ware. This was a lot of inspection and there always seemed to be considerable difficulty with bad or shady products in the following department. It is necessary here to clean the product preceding the welding operation. We started a Quality Control program by removing four of the inspectors. A conveyor was installed following the washer, where we placed one of the inspectors with a chart, this chart to run for a period of a week and is available for operators to see. Following the inspector, the timekeeper was provided with a scale on the conveyor. Operators were informed that they would be paid piecework for the ware that passed inspection and that rejected material would be returned to them. The other inspector was supplied a cart with a chart and scrap pan. He was to make four trips around the department each shift to clean out the scrap pans and also pick up all bar ends. Operators must account for bar ends. The machines are capable of cutting the bar stock to a four inch stub. Anything in excess of four inches was charged to the department as scrap. Previous to gathering and accounting for the bar ends, they were supposed to be placed in a container, but instead they were thrown into the chip conveyor which is underground. Breaks in the chains of the conveyor were constantly occurring. Result of the change, the conveyor has not broken in over two years. Savings due to the Quality Control program cannot be figured here.

For measuring the product now, the Quality Control operator is equipped with an electric gaging machine that checks six points on the shell:

Counts the number of pieces fed to the machine;

the number accepted;

the number rejected;

whether positive or negative; and sorts into groups.

With the use of this equipment and air gages through this department we have shown considerable progress. The use of tighter and better measuring equipment will not, as expressed by many, lead to higher costs and rougher operation of a department. As found in our organization, it gives a better product with which to work in the following departments and longer tool life. One can take full advantage of the allowable tolerances and in many cases have them broadened. There are many inefficiencies in inadequate measuring equipment.

For final inspection, or Quality Control of the finished product, we have one operator on each shift who spends the entire eight hours selecting trays of spark plugs from the assembly line. This is a point where we exceed Military Standard 105-A in sampling, previously mentioned. These trays are gone over 100%. A chart is drawn up for the defects that are considered critical, major and minor. They list everything for which we want them to look. From this we figure our average outgoing level.

The Quality Control operator gives hourly reports to the Department Foreman as to defects detected. If critical or major, a complete survey of the assembly line is made to remove the defective ware and the operation corrected.

The functions of the Quality Control Department extend far beyond the measurement of sizes. The parts used for spark plugs are small. They are dropped easily and fall through roll conveyors. Catch pans were installed at intervals on the conveyors and this created a problem of removal of the dropped articles, cleaning and sorting. We suggested that funnel type catch-alls with a drip pan be installed under the assembly lines. Now when a run on a type is completed, or at the end of the shift, it is the operator's responsibility to empty the drip pan. It is surprising how few pieces are in the pan and sorting due to carelessness is eliminated.

We pay the operators for removing scrap, but not scrap from their own or the preceding machine. It must be defective from a preceding department. This is accomplished by the Quality Control personnel issuing a credit slip to the operator which is picked up by the timekeeper.

Scrap from all departments is moved into an enclosed area next to the Inspection Office at the end of each shift. The General Foreman, Department Foremen and Chief Inspector hold weekly meetings regarding the scrap. In some cases the Plant Manager or his Assistant attends. The scrap is scrutinized, along with the scrap reports. Efforts are then directed toward the jobs giving the most trouble. The material is then disposed of and a new lot started.

The Inspection Office is very centrally located in the plant and the employees pass by when entering or leaving. We keep histograms and current charts of the departments posted in the windows. These draw considerable attention. Another means of publicity we use for Quality Control are colored cards with short pointed phrases on Quality posted throughout the shop. When defective spark plugs are returned from our customers, they are mounted on display boards with comments the customer may make. If none, we supply some. These are posted in the various departments and in the display window of the Quality Control Office. I believe, like the merchant on Main Street, that in

order to sell a product or program it must be advertised. Quality Control must be sold, not to Management, - they want Quality; but to the only people who can control Quality in the plant - the production operator.

Along with publicity in the shop, we make weekly and monthly reports to plant Management. These reports are always charts, not the detailed charts used on the machines, but a progress chart comparing last weeks or last months production and scrap as against this weeks or months results. Thses charts must be clear and to the point. I mean not complicated, or a busy man will not take time to analyze them. By short notes we point out the high or low points. We use a color code (black for first shift, red for second and purple for third) with explanatory notes in the right hand lower corner. We never fail to receive some comments on these publications. Generally, we do not hear direct from the Manager. He contacts the department heads and our inquiries come from the Department Foremen, the Assistant Plant Manager, the Engineering Department and the Ceramic Division.

Gages receive much attention. Each has its card in the file from the time of purchase. Numbers used only by the Inspection Department, are assigned and a complete record kept on their use. All thread and measuring gages are checked every eight hours. Auto-Lite contact men calling on customers are given gages supplied by the Inspection Department. These are returned at regular intervals for replacement. In this manner we know that everyone is working with uniform gages. All plug and ring gages are being replaced with measuring equipment which has greatly increased tool life and gives us much better control.

A Quality Control program definitely cannot be worked out and installed in a short period of time. It must be sold, as I before stated, to the people at the production machine. Scrap can be reduced in unbelievable amounts, which automatically increases production and reduces costs. The scrap loss in our organization in the last three years, where the strength of our program is being felt, has been reduced 35% over the whole plant.

CONTROLLING THE QUALITY OF BONDED PANELS- HONEYCOMB AND LAMINATE TYPE

H. B. Epstein
Chance Vought Aircraft, Incorporated

Chance Vought Aircraft has been fabricating bonded assemblies as primary structural members in propeller driven aircraft, jet aircraft and guided missiles for over 12 years. Their experience has been with principally three basic adhesive systems and with virtually all bonded forms. Yet from this very diversified experience one principal quality control concept has developed, regardless of the details of fabrication. This concept states that, "unless detailed basic process controls from raw material through to final inspection of the completed panel are exercised, the part has not been effectively quality controlled."

Unfortunately, to this very day the major gap in controlling the quality of bonded construction of any type is the lack of a means for determining marginal strength bonds in completed parts. What we have been able to do by controlling all process details is to reduce the probability of occurrence of marginal bonds and to detect gross voids, but our method for detecting marginal bonds, should they occur, remains personal with the inspector and not very scientific.

To be sure, our experience has convinced us that process controls have given us a high degree of reliability in bonded assemblies, as attested to by a great deal of field experience, but in this adhesive field we remain very dependent on the statistics for predicting strength levels and probability of marginal bonds as a means of determining acceptability.

With the increased popularity of bonding as a structural fabrication method it becomes more and more urgent that means be developed on a production basis for evaluating the bond in a completed part. Until this gap is filled the facts determining the acceptability of bonded parts will continue to be purely circumstantial.

MILITARY APPLICATIONS OF OPERATIONAL RESEARCH

J. W. Abrams
Royal Canadian Air Force

Organized military operational research was initially applied by the Royal Air Force at the very outset of the 1939-45 war. Its worth to the armed services was rapidly appreciated, and it was not long before operational research sections appeared throughout the British Services and in those of the United States and Canada. They have remained with these services and similar organizations have been established in other countries as well. Isolated examples of operational research can be given from earliest times, but the "accident of fate" which led to the birth of organized operational research was the introduction of radar. The R.A.F., in particular, was confronted with a new - and presumably critically important - device, and the political situation was such that they had to learn how best to employ it in the shortest possible time. To speed up this process, scientists were brought in to test experimental "bread-board" equipments under anticipated operational conditions. They remained on during wartime.

In order to carry out field tests these first operational research scientists found it necessary to ask many questions which did not fall within their normal scope of enquiry. They became involved in questions which traditionally had been more restricted to the military, such as how best to employ radar in order to gain the maximum tactical value, and they became deeply concerned with many aspects of tactics and strategy. It was not long before they were specifically asked for advice by commanders, and their investigations were used as part of the basis for operational decisions. The formal establishment of operational research came with this shift in emphasis from the technical to the operational.

One of the earliest instances of co-operation between operational research scientists and the military was an investigation undertaken by the Operations Research Section of R.A.F. Fighter Command at the instigation of the A.O.C. in C., Air Chief Marshal Sir Hugh Dowding. Sir Hugh was concerned over the loss rate of R.A.F. fighters at the time of the German break-through into France and the Low Countries. He was responsible for maintaining his Command in being as a fighting entity, but was being urged to expand its field of battle into France to re-inforce the sorely pressed forces there. He turned to his operational research section for advice.

The problem was simplified, stripped of all except measureable factors, and set up as a mathematical model. Inputs were such factors as loss rate, number of expected engagements, and production rate. Results showed that the strength of the Command would soon be dissipated if reinforcements were sent, whereas, if the forces were concentrated at home under favourable conditions, they would increase in strength. Operational research workers like to feel that by accepting the mathematical model as adequate, and acting accordingly, Sir Hugh built up the strength of Fighter Command so that it was able to defeat the Luftwaffe at the next critical engagement - the Battle of Britain.

The early course of operational research was not smooth; the trend of acceptance was gradual, but it was steady. It developed because the

operational research worker was able to complement the training and background of the military commanders, and the benefits of this complementarity were tangible.

The military commander is an executive. He is trained to make decisions rapidly and mostly irrevocably. He realizes he may make mistakes, but recognizing that no decision is in itself a decision, he must be prepared to act. When possible, he prepares for his decision through staff work - a study in which all the factors which may affect the decision are laid bare and presented to the commander in a briefing. These staff studies are prepared by staff officers, themselves training for eventual command. Rarely, if ever, is there time for a staff study to be definitive; in general, the decision is taken on the best evidence that is available at the time the decision must be taken. The commander must endeavour to obtain an overall appreciation of the situation confronting him; he must weigh the known and measureable factors, appreciate the imponderable and unknown ones, and then he must act.

The research scientist lives in a different world. He has been able to reduce the physical world to measureable quantities, and he generalizes his results in mathematical models. He is not pressed for time in the same manner as is the commander, and does not draw his conclusions - which constitute the counterpart of the commander's action decisions - without definitive study and collection of all relevant facts. While the staff officer must learn when to stop investigation and prepare his brief, lest the decision be made before the brief can be presented, this aspect is not part of the scientists' usual considerations; it is one that the operational research man must learn.

The scientist, however, can make tremendous contributions to staff studies. First, the scientist - irrespective of his field of specialization - has his methodology. Second, he has his techniques which enable him to abstract, set up, and solve problems. The technical tools, such as the various branches of mathematics, which the scientist possesses lead him to make contributions to staff studies which would not otherwise be present. The scientist's form of staff study - i.e. the operational research study - is conditioned by his knowledge of the methods of attack found useful in the physical and biological sciences. He can abstract the elements of tactical problems and formulate them so that they are amenable to known methods of solution.

Yet the scientist is no perfect staff officer, and his operational research study is no complete solution to the commander's problem. Physical science is simple; it concerns itself with measureable and predictable quantities. The scientist will, as Mr. Larnder did in the example above, make a mathematical model of the tactical problem and then proceed to solve it. If all the significant factors can be placed in the model - that is, if all the actions of one's own forces and the enemies are either known and predictable, or irrelevant - then, and then only, does the result of the operational research study constitute the action that the commander should take without question. More often than not this is not the case, and the mathematical solution may not necessarily apply to the real case. It is the commander's responsibility to determine the degree of applicability of the operational research study.

A great deal of the initial value of operational research arose from the introduction of a fresh outlook. Some problems were solved which in retrospect seemed absurdly simple, but which had not been solved because those concerned had been too close to them. A classic instance is that of the air-dropped depth charge in anti-submarine warfare, which was solved by Professor P. M. S. Blackett, a Nobel Laureate in Physics; one of operational research's foremost pioneers.

When first employed by aircraft against submarines, the depth charge killed far fewer submarines than was expected. Blackett and his coworkers set out to determine wherein the weaknesses lay. From an examination of records of all attacks an obvious mismatch was found. The depth charges were set to go off from 50 to 150 feet, while analysis showed that in most cases the submarine at time of attack was so close to the surface that these attacks could do no more than shake it up. When the distribution of submarine depths at time of attack was determined and put into a mathematical model it was recommended that the depth charge should be set to explode at 25 feet to yield the maximum of kills. This was done, and the lethality of attacks doubled within a short time.

Simple - of course! But the answer only emerged after the scientist, following his methodology of analysis, set in motion the machinery to collect the data for the model.

Blackett's successors did not stop at this point. They recognized that it was almost as good operationally to damage a submarine so that it could no longer be effective and could not return to base as it was to kill it instantly. Now a depth charge, which has a lethal radius of x yards, will have a crippling damage radius of y yards where y is greater than x. Depth charges were customarily dropped in a stick with spacings 2x, so that they would kill any submarine which lay within their bombardment pattern. While this pattern would kill submarines if properly placed, it was optimal neither for killing the most submarines nor for preventing the most from continuing operations. Analyses which now included the statistical distributions of bombing errors in operations indicated a different spacing was optimal. Unlike Blackett's solution, which was self-evident when found, this one was far from superficially obvious. When adopted, however, it was verified under fire and a gratifying increase in air anti-submarine effectiveness resulted.

The examples above may indicate how the scientist's approach to aspects of military problems provided something which had been missing in previous staff work. In the first case, the new factor lay in the method of approach; in the latter, a specific technique, the mathematics of probability and statistics, was employed as well. Probability mathematics were the first technique to be extensively employed in military operational research. They were used to determine optimal bombing patterns for mass raids, best methods for the employment of submarines, and for the solution of many other problems. As these solutions were put into practice the complementarity of the scientists and the military man became better understood, and military operational research found its niche in operations.

Search theory was another technique which found early application. Abstracted to essentials the problem of search consists of determining how best to find a sought object, given the knowledge of its probability

distribution about a given datum at a known time subject to constraints imposed by the position and mobility of the seeker. If the object sought is fixed in space or moves with a known velocity, the problem is simple. When the sought object moves with unknown velocities, the problem is less simple, and when it attempts thinking evasive manoeuvres, it becomes most complex. Yet it is a real military (or more frequently naval) problem, and one amenable to operational research analysis.

Solutions to search problems found their way into tactical doctrine books. The investigations highlighted a pitfall of operational research; namely, that the solution may be real, exact, and impracticable. The simplest of search problems, which is found in many elementary calculus books, calls for the searcher to steer a course following a logarithmic spiral. This is completely impracticable for ships or aircraft. While this case is trivial, operational situations are similar and differ only in being more complex. For his solutions to be of value the operational research scientist must add the additional constraints to his model which are imposed by the limitations of the equipment at hand. To do this, it was necessary - and still is - for operational research workers to go into the field, to fly in combat aircraft, to operate radars, to live with the fighting men, in order to place realistic limitations on their mathematical models.

Study of the capabilities of equipment is a natural field for operational research. There are many situations, otherwise overlooked, which become evident through an analysis of operations performed either in the field or in the laboratory with the use of field data and an appreciative understanding of field conditions. Field conditions are not laboratory conditions. Field operators are not laboratory engineers. Field maintenance men are not laboratory technicians. The fact that a radar set has a certain potential of detection under ideal conditions, does not mean that it has the same capability under operational conditions. The commander must know what he can reasonably expect from his men and equipment, and operational research can help him to determine this. Such evaluations are not limited to an assessment of equipment. Fatigue, operational schedules, personnel, and training questions also enter. The results of such operational research evaluations are of three types:

(i) They show the commander what he can expect his forces to accomplish, and enable him to prepare and execute plans.

(ii) They point out the obvious weak points in the system, and permit improvements to be made.

(iii) They serve as a guide to set up the requirements for replacement equipment, and for development.

This last type of product is particularly significant for peacetime military operational research.

The solutions to general search problems depend on the behaviour of the sought object. Translated to military terms this is the truism that one's best tactic depends upon what the enemy does. The commander would love to have foreknowledge of what the enemy intends to do, but this is rarely granted him. The problem for him is to maximize what he can do

to the enemy while undertaking minimum risk - the so-called minimax solution. His tactical position can be greatly clarified by the representation of the results of possible courses of action in a matrix. Such tactical analyses can make clear to the commander the consequences of various courses of action (in the ideal situation) and assist him in balancing "pay-off" against risk.

Techniques of analysis which involve a measure of ignorance as to enemy intent or capability are within the scope of the growing mathematical field of "games-theory". Games-theory itself was developed to handle economic problems, but its applicability to tactics and strategy were immediately evident. Although the field has greatly progressed and expanded since von Neumann and Morgenstirn's original book on the "Theory of Games", operational research workers have not as yet been able so to reduce real tactical or strategic situations of any great import to the degree that they can be solved in general by games-theory. Nevertheless it has made a considerable contribution to operational research in that the man familiar with the principles of games-theory gains insight into the generalized problems of tactics and strategy and is thereby better able to set up his models in specific cases. Similar comments can be made for the newly developed theories of value and of decision. We are just beginning to use all of them.

Military operational research in peacetime is a more tranquil life, only in respect to the fact that we are not bombed nor shot at. The pressure to produce results and decisions to a time scale is no less intense. Technology is progressing at a fantastic rate, especially in the fields of electronics and aeronautics, and each technical advance has military implications. A hypothetical example of peacetime problems, particularly with respect to new weapons, may be illustrative.

Let us suppose that technical advancements in offence are such that our current missile is no longer adequate. One may say, for example, that it is too slow or perhaps of inadequate range, or accuracy, or hitting power. One of the ways in which we will learn of this inadequacy is when the new threat is examined as part of the operational research study on current weapons. In general - but not always - the inadequacy will be apparent, but the operational research model will yield a quantitative measure. With this as a guide it is possible to set up a realistic operational requirement from which the characteristics of the new missile can be drawn.

When the military characteristics are passed to the development agencies or contractors, one or both of two likely situations may arise.

(i) The function may be performed equally well by any of a family of missiles, differing in size and range. It is necessary to determine by analysis the optimal values of these parameters, so that the function can be performed most economically.

(ii) Inasmuch as a perfect missile would pack infinite hitting power with no weight to a distance of halway round the earth with complete accuracy, we should not be surprised to find our real missiles falling short of this in some respect. When this is the case - i.e. always - we must choose between certain antithetical parameters such as

weight and hitting power in order to strike the balance which represents the best missile which is within our capability to produce.

The processes above are examples of sub-optimization. It is necessary for the process to go further. No weapon acts alone; all are part of what we term a weapons system which includes, in the case of an air defence system, radars, base complexes, communications systems, aircraft, fire control systems, etc., as well as actual missiles, rockets, guns and bullets. Sub-optimization relates to a component of the system; optimization to the system as a whole. To achieve optimization is the go al of every military planner, and the results of operational research assist him in this task. It may be noted that reference is made here to the military planner rather than the commander as was done earlier; this is a reflection of the peacetime role.

A weapons system is most effective when tailored to its environment. In the case of defence systems, the effectiveness depends on the placement or disposition of the component elements as well as the enemy's tactics. The optimum theoretical disposition can be calculated through the medium of war games; a technique in which every possible tactic can be tried out against every possible defence disposition. From war gaming one can learn the best disposition to use against any specific offence, as well as the minimax solution for all offences. The war game is in part an abstracted successor to the traditional sand table on which tactics were developed. The number of repititive processes which could be carried out if one exhausted possibilities in a war game is so great that heretofore only a fraction of the possibilities were investigated. Electronic computers and Monte Carlo techniques are making exhaustive studies possible and profitable.

Equipment layout, time and motion study, and some measure of human engineering are associated with operational research. While they have been carried out by operational research workers in the past, their practice is not strictly operational research. Nevertheless, it is frequently the operational analysis which is used to point to the need for studies along these lines.

During the War, Dr. Cecil Gordon studied the relation between the number and distribution of hours flown and the requirements for aircraft maintenance. He worked out an optimal scheme for flying and maintenance which greatly reduced the manpower required. Postwar, similar studies have been made by transport companies, particularly in Britain, with profitable results. Contrary to what is probably popular belief, the military machine under operational conditions is a highly efficient one with little waste effort. Studies of this type are constantly made by operational research workers on all types of equipment, in order to improve effectiveness.

The R.C.A.F. may serve as an example of the place that operational research has found in a military organization. In it, operational research, where applicable, has been integrated with normal staff evaluative and decision-making procedures both at Headquarters and in the operational Commands. Two directorates and one section have been established in AFHQ, each of which deals with a different aspect; one deals with current operational problems, one with planning and the third with manpower and utilization problems. In addition, Operational Research

Branches exist at the Commands for the purpose of advising the Air Officers Commanding. Scientists are attached from the Defence Research Board Operational Research Group - which provides them for all three armed services as well as for its own sections - and work alongside uniformed personnel with appropriate backgrounds. Finally, there is a Scientific Adviser to the Chief of the Air Staff, who ensures that the required studies are undertaken and the responsible R.C.A.F. officers advised of the results. The relationships established and results obtained have been most satisfactory.

I have endeavoured in the above to show how operational research, which may be called a method by which management (or command) is provided with a quantitative aid in formulating decisions, has found its place in the military organization. To a large extent I believe this is a successful venture because of the complementarity in backgrounds of the scientist and the executive. The field is a fertile one and, as more applicable techniques are developed, I am confident it will continue to produce profitable results.

EXTENDING THE APPLICATION OF MATHEMATICS IN INDUSTRY

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Industry has increased its use of mathematical techniques at a rapid rate since World War II. We in A.S.Q.C. have been particularly aware of the growth of these techniques in the statistical field. Statistical methods have played their greatest role in the control and inspection of product quality. However, they are becoming commonplace in other industrial areas such as experimented design, industrial engineering, cost control, consumer surveys, office procedures, and business administration. In fact, some of the statistical methods less known to the quality control engineer are making more frequent appearances in industry. Examples of these are waiting line (queueing) theory and the Monte Carlo method.

Waiting line probability theory is useful in studying delays encountered at a servicing point. For instance, it furnishes a procedure for determining from a cost standpoint the optimum number of mechanics needed to service a given number of machines. We have seen the value of the Monte Carlo method of drawing chips from a bowl in demonstrating the functioning of a control chart. It is being used to demonstrate the validity and practicality of other statistical theory, and is enabling us to solve problems where present known theory is inapplicable or impractical to apply. High speed computers are adding to the usefulness of this method.

There exists a great future for extending the application of statistical methods in industry. Few companies have solved even a portion of their statistical problems, and the solution of some of these problems demands further fundamental and applied research. The current statistical literature is filled with attempts to satisfy industry's need, but the quality control engineer finds it difficult to keep informed of the available literature and to apply it to his own operations. His job is being further complicated because many of the mathematical problems he is asked to solve and much of the literature he is expected to understand are outside the statistical field.

The Role of Quality Control Engineer

What then is the role of the Q. C. engineer in this increased use of mathematical techniques? We have said that he is probably unable to keep abreast of all the current literature now directed toward the application of mathematics to industrial problems. Extending the use of the S. Q. C. techniques is a full time job. Yet, competition demands that a company be ever alert for improved methods of operation in all fields, and these new methods are paying off when applied judiciously. Hence, the average company must obtain additional help by hiring personnel capable of understanding and applying the new methods, hiring consulting service, training present personnel, etc. Applying these new theories to business generally is a team affair, and the Q. C. engineer is a vital man on the team selected to make the applications in his areas.

Much inertia to wide spread use of the new mathematical techniques is due to the inability of management personnel to either recognize the

need for them, know where to find them, or to appreciate their worth after they are found. The Q. C. engineer is in a fine position to make a significant contribution to further promotion of the use of mathematics in industry. He has seen first hand what the quantitative, statistical tools have accomplished in the control of product quality. He should gain sufficient familiarity with some of the new techniques appearing in the literature to be able to appreciate their worth and to recognize where they may apply in his company. Thus, the Q. C. engineer should keep a watchful eye for new techniques, an open mind toward them, and not hesitate to engage the services of specialists when the problem requires them.

The Role of the Mathematician

T. C. Fry (2) points out that the role of the mathematician in industry is not one of solving problems. He is usually not good at this job, certainly not as good as a machine. The indispensable function of the mathematician is in helping formulate problems because he is trained to critically analyze relations and concepts. Hence, he as well as other specialists should be brought into the problem solving team early if they are to be most effective. These specialists are needed all too often on problems covering extensive areas of operations and management because these problems have a knack of being different, and their solution frequently takes time and a rather unique and fundamental approach.

It is important that the nature and scope of the problem determine the method of solution and that we not limit the problem by insisting upon a specific method. The advent of high speed computing machines permits us to use methods which were previously impractical. The need for limiting the number of variables and imposing restrictive assumptions has decreased. At the same time we should not sell short the approach of seeking to unearth problems which fall within the scope of specific techniques. The application of the control chart to process control has been done largely in this manner. Thus, a company should have available a variety of techniques along with fundamental knowledge of these techniques both for searching out the problems and for obtaining the most desirable solutions for them. The references at the end of this paper form a short reading list recommended to the Q. C. engineers for gaining familiarity with some of the common techniques, many of which are referred to under the heading of Operations Research.

Linear Programming

One of non-statistical, mathematical techniques having unusual success in industry is Linear Programming. It has wide applications in the scheduling of production and shipments. A. E. Paull (7) applies this method to two newsprint scheduling problems:

(1) To determine the customers to be supplied from each of a series of mills in order to minimize the overall freight costs, and

(2) To determine the combinations of roll widths to run on a newsprint machine in order to manufacture the required numbers of each roll width with a minimum of trim waste.

The purpose of the remainder of this paper is to apply linear programming in the solution of two problems. The conditions are simplified

so that the method can be more easily understood. In the first problem we are producing two grades, X and Y, of paper on a paper machine. Due to raw materials restrictions not more than 400 tons of grade X, and 300 tons of grade Y can be produced in a week. Let the numbers of tons of grades X and Y produced during the week be denoted by x and y respectively. Then,

$$x \leq 400 \text{ and } y \leq 300.$$

It requires 0.2 and 0.4 hours to produce a ton of product X and Y respectively. Since there are available 160 production hours each week,

$$0.2x + 0.4y \leq 160 \text{ or } x + 2y \leq 800.$$

The profit Z for the week is given by the function

$$Z = 20x + 50y,$$

showing the profit to be \$20 per ton of X and \$50 per ton of Y. The problem is to determine the values of x and y which maximize the profit function

$$Z = 20x + 50y,$$

subject to the restrictions,

$$x \leq 400$$
$$y \leq 300$$
$$2y + x \leq 800$$

This is essentially the problem described graphically in reference (4).

Since $x \geq 0$ and $y \geq 0$, the value of x and y must fall on the boundary or within the polygon enclosed by the lines $x = 0$, $y = 0$, $x = 400$, $y = 300$, and $x + 2y = 800$. The optimal solution occurs at a corner because Z is a maximum when the family of parallel lines $Z = 20x + 50y$ are as far as possible from the origin.

FIGURE I

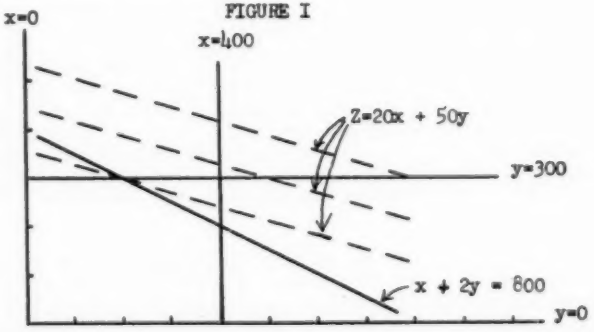

Figure I shows the corner to be $x = 200$, $y = 300$, or (200, 300). Hence, the maximum

$$Z = 20(200) + 50(300) \text{ or } 19000$$

If the line $Z = 20x + 50y$ had been parallel to one of the sides of the polygon, say $x + 2y = 800$, then the optimal values of x and y could fall any place on the line $x + 2y = 800$ between the vertices (200, 300) and (400, 200).

Simplex Method

The graphical method of solution works well for two independent variables x and y, but another method of solution must be called upon in the typical industrial problem involving four up to twenty or more independent variables. Dantzig (1,3) developed an algebraic method, called the "Simplex Method" for solving such problems, and it is used in this example. First, the inequalities are made into equalities by introducing non-negative and zero valued slack variables s_1, s_2, and s_3:

$$(1)\qquad \begin{aligned} x + s_1 &= 400 \\ y + s_2 &= 300 \\ x + 2y + s_3 &= 800 \end{aligned} \quad \text{or} \quad \begin{aligned} 1{\cdot}x + 0{\cdot}y + 1{\cdot}s_1 + 0{\cdot}s_2 + 0{\cdot}s_3 &= 400 \\ 0{\cdot}x + 1{\cdot}y + 0{\cdot}s_1 + 1{\cdot}s_2 + 0{\cdot}s_3 &= 300 \\ 1{\cdot}x + 2{\cdot}y + 0{\cdot}s_1 + 0{\cdot}s_2 + 1{\cdot}s_3 &= 800 \end{aligned}$$

We set up these equations in matrix form and bound them on the left with the slack variables. The entire configuration (shown in Table I) is then bounded at the top and left by the c's which are the profits per ton of X, Y, s_1, s_2, s_3, and r, and are equal respectively to 20, 50, 0, 0, 0, and 0.

TABLE I

c →		20	50	0	0	0	0
↓		x	y	s_1	s_2	s_3	r
0	s_1	1		1			400
0	s_2		1		1		300
0	s_3	1	2			1	800
	z	0	0	0	0	0	0
	z-c	-20	-50	0	0	0	0

The z's are the sums of the products of each element in the particular column and the c on the left in the same row as this element. For example, in Table I, z_x in the x column is equal to $1{\cdot}0 + 0{\cdot}0 + 1{\cdot}0$ or 0. The value $z_x - c_x$ equals 0 - 20 or -20, where the c_x of 20 is obtained from the top row in the x column. The terms in the z-c row are called indicators, while the terms in the r column are called requirements. The equations and the matrix must be expressed in such a form that the requirements are positive.

The slack variables s_1, s_2, and s_3 were introduced to give a unit matrix which forms the basis for beginning the solution of the problem. Each basis variable must have a positive coefficient of 1 and appear in only one of the equations. A solution to the problem by the simplex method is found by letting basis variables equal the corresponding requirements and the non-basis variables equal 0. From Table I the first solution is: $s_1 = 400$, $s_2 = 300$, $s_3 = 800$, $x = 0$ and $y = 0$. It satisfies Equations(1) and graphically represents the vertex (0, 0) of the

polygon in Figure I. The z_r in column r denotes the profitability associated with this solution. A solution gives a maximum profit only when all of the indicators are zero or positive. Our first solution is not a maximum because

$$z_x - c_x = -20 \text{ and } z_y - c_y = -50$$

The smaller of the two negative indicators, that is $z_y - c_y$, designates that the y variable should be introduced into the basis to replace one of the s's. To facilitate the explanation, the numbers in Table I are replaced with the letters a_{jk} as shown in Table II with the z row deleted. The indicators in the z - c row are represented by a_{ix}, etc.

TABLE II

c →		20	50	0	0	0	
↓		x	y	s_1	s_2	s_3	r
0	s_1	a_{1x}	a_{1y}	a_{11}	a_{12}	a_{13}	a_{1r}
0	s_2	a_{2x}	a_{2y}	a_{21}	a_{22}	a_{23}	a_{2r}
0	s_3	a_{3x}	a_{3y}	a_{31}	a_{32}	a_{33}	a_{3r}
z - c		a_{ix}	a_{iy}	a_{i1}	a_{i2}	a_{i3}	

To determine the s_i to be replaced by y in the basis, divide each positive quantity a_{1y}, a_{2y}, and a_{3y} into the corresponding a_{1r}, a_{2r}, and a_{3r} to obtain ϕ_{1y}, ϕ_{2y} and ϕ_{3y}. In our example, only a_{2y} and a_{3y} are positive numbers. Hence,

$$\phi_{2y} = a_{2r} / a_{2y} = 300 / 1 = 300$$
$$\phi_{3y} = a_{3r} / a_{3y} = 800 / 2 = 400$$

Since ϕ_{2y} is the smaller, y should replace s_2, the basis variable in the same row as a_{2y} and a_{2r}. The term a_{2y} is called the pivot. The next step is to generate from the matrix in Table I a second matrix having s_1, y, and s_3 in the new basis. The new matrix is shown in Table III. In the new transformed matrix the elements in the y row are found by dividing each element in the s_2 row of Table I and II by the pivot which is a_{2y} (or 1 in Table I). When this division is carried out, a^{-1}_{2y} the transform of the pivot must be 1, of course, regardless of the value of the pivot. All other elements in the new y column are 0. To find the transforms of those elements not in the pivot row or pivot column, consider the following diagram representing elements in Table I or II:

We wish to find transform E^1 of element E. P denotes the pivot, C the element in the same column as P and the same row as E, and R the element in the same row as P and the same column as E. We find the product of R and C and divide it by P. The quotient is subtracted from E to give E^1. That is,

$$E^1 = E - \frac{R \cdot C_r}{P}$$

Thus, the a^1_{1x} in Table III is given by the formula,

$$a^1_{1x} = a_{1x} - \frac{(a_{2x})(a_{1y})}{a_{2y}}$$

$$= 1 - \frac{(0)(0)}{1} = 1.$$

The other elements of Table III are found in a similar manner. For example,

$$a^1_{3r} = a_{3r} - \frac{(a_{2r})(a_{3y})}{a_{2y}}$$

$$= 800 - \frac{(300)(2)}{1}$$

$$= 200$$

TABLE III

c →		20	50	0	0	0	0
↓		x	y	s_1	s_2	s_3	r
0	s_1	1		1			400
50	y		1		1		300
0	s_3	1			-2	1	200
	z - c	-20	0	0	50	0	15000

Table III shows that Equations(1) has been transformed into a new set of equations:

$$(2)\quad \begin{array}{l} 1 \cdot x + 0 \cdot y + 1 \cdot s_1 + 0 \cdot s_2 + 0 \cdot s_3 = 400 \\ 0 \cdot x + 1 \cdot y + 0 \cdot s_1 + 1 \cdot s_2 + 0 \cdot s_3 = 300 \\ 1 \cdot x + 0 \cdot y + 0 \cdot s_1 - 2 \cdot s_2 + 1 \cdot s_3 = 200 \end{array} \quad \text{or} \quad \begin{array}{l} x + s_1 = 400 \\ y + s_2 = 300 \\ x - 2s_2 + s_3 = 200 \end{array}$$

Equations(2) may be calculated directly from Equations(1) by replacing y in the third equation of (1) with its equal in the second equation. The first two equations remain unchanged. Even if this method is used, some system involving indicators is necessary to show the step to take next and when an optimum solution is reached.

The new matrix in Table III has moved the solution from vertex (0, 0) to (0, 300). We see from the indicator in the r column that the profit has increased from 0 to $15000. However, the x indicator of -20 implies that a maximum profit has not been reached. Repeating the steps above, we find that x must replace s_3 in the basis and a new matrix shown in Table IV is obtained. The equations represented in Table IV may be calculated readily from Equations(2).

We observe that all the indicators in Table IV are zero or positive

insuring that the solution, $x = 200$, $y = 300$ produces the maximum profit, \$19,000. The slack variable s_1 equaling 200 shows that x is 200 short of its limitation in the inequality $x \leq 400$. The indicator 10 implies that each unit increase in s_2 (this is equivalent to a unit reduction in the s_{2r}), reduces the profit by \$10. For example, if s_2 is increased 100 which insists that $y \leq 200$ instead of $y \leq 300$, then the new maximum profit solution is (400, 200) and the profit Z becomes $20(400) + 50(200)$ or \$18,000, a reduction of 100 (\$10) from the previous maximum profit of \$19,000. Similarly, the indicator 20 implies that if we increase s_3 by 100 and force $x + 2y \leq 700$, then the new maximum profit solution is (100, 300) and the profit is reduced by 100 (\$20) or \$2,000 from the previous figure of \$19,000. These indicators represent the rate of change in the profit for changes in s_2 and s_3 as long as x, y, and s, remain in the basis for the maximum profit.

TABLE IV

c →		20	50	0	0	0	0
↓		x	y	s_1	s_2	s_3	r
0	s_1			1	2	-1	200
50	y		1		1		300
20	x	1			-2	1	200
	z-c	0	0	0	10	20	19000

Simplex Method to Find a Minimum Solution

The Simplex Method was applied to maximize a profit function in the above example. We shall now show how the method is used to minimize a function of a series of variables subject to certain constraints. A cattle feeder wishes to purchase four special feeds F_1, F_2, F_3, and F_4 in order to supply the proper vitamin content to his feed mix. Table V gives units of vitamin content in a pound of each type of feed and the cost per pound of the feed.

TABLE V

	A	B	C	Cost/lb.
F_1	4	1	0	2 cents
F_2	6	1	2	5 cents
F_3	1	7	1	6 cents
F_4	2	5	3	8 cents

The feed mix must contain at least 12 units of A, 14 units of B, and 8 units of vitamin C. If x_1, x_2, x_3, and x_4 denote the numbers of pounds respectively of F_1, F_2, F_3, and F_4, then

$$
(3)\qquad
\begin{aligned}
4x_1 + 6x_2 + x_3 + 2x_4 &\geq 12\\
x_1 + x_2 + 7x_3 + 5x_4 &\geq 14\\
2x_2 + x_3 + 3x_4 &\geq 8
\end{aligned}
$$

The total cost Z in cents of these feeds is

$$Z = 2x_1 + 5x_2 + 6x_3 + 8x_4$$

The problem is to minimize Z subject to the restrictions given in Equation (3). Non-negative, zero valued slack variables s_1, s_2, and s_3 are introduced into Equation (3).

$$
(4)\qquad
\begin{aligned}
4x_1 + 6x_2 + x_3 + 2x_4 - s_1 &= 12\\
x_1 + x_2 + 7x_3 + 5x_4 - s_2 &= 14\\
2x_2 + x_3 + 3x_4 - s_3 &= 8
\end{aligned}
$$

No one of the variables in Equations (4) satisfies the necessary conditions to be in the basis, i.e., having a coefficient of +1 and appearing in only one equation. Remember the requirements, 12, 14, and 8 must remain positive. It is possible through algebraic manipulation to modify the equations so that some of the variables may serve in the basis, and this would be wise in many cases. However, we shall merely add a new set of non-negative variables t_1, t_2, and t_3 to the respective equations in (4) to form the basis for applying the simplex method. We obtain:

$$
(5)\qquad
\begin{aligned}
4x_1 + 6x_2 + x_3 + 2x_4 - s_1 + t_1 &= 12\\
x_1 + x_2 + 7x_3 + 5x_4 - s_2 + t_2 &= 14\\
2x_2 + x_3 + 3x_4 - s_3 + t_3 &= 8
\end{aligned}
$$

These t_1's are artificial variables and must be zero in the final solution. In order to insure that they will be removed from the basis and made zero in the optimal solution, they are made infinitely expensive and given values M.

The matrix configuration for this problem is similar to the one in Table I and shown in Table VI.

TABLE VI

c →		2	5	6	8	0	0	0	M	M	M	0
↓		x_1	x_2	x_3	x_4	s_1	s_2	s_3	t_1	t_2	t_3	r
M	t_1	4	6	1	2	-1			1			12
M	t_2	1	1	7	5		-1			1		14
M	t_3		2	1	3			-1			1	8
	z-c	5M	9M	9M	10M	-M	-M	-M				34M
		-2	-5	-6	-8							

Since we wish to find values of x_1, x_2, x_3, and x_4 which minimize rather than maximize the cost function Z, the optimal solution is found only when all of the indicators are zero or negative. The largest positive indicator, 10M -8 in Table VI implies that x_4 should replace one of the t's in the basis. To determine the t to be replaced from the basis and to find all of the elements in the new matrix, we proceed in exactly the same manner as in the previous problem when we maximized z. Table VII gives the three matrices which are derived as we move to the optimal solution. For the optimal solution,

$x_1 = 0$
$x_2 = 106/77 = 1.3766$
$x_3 = 8/11 = 0.7275$
$x_4 = 116/77 = 1.5065$, and
$z = 23$ and $23/77$ cents

The indicators in Table VI for the optimal solution have the same meaning as in Table IV. For example, if s_1 is increased by 1 unit and, thus, the number of A vitamins required reduced from 12 to 11, then the minimum cost Z is reduced by 18/77 cents from the previous minimum cost of 23 and 23/77 cents. These rates of change in the minimum Z with changes in the s's would continue as long as x_2, x_3, and x_4 remain in the basis of the optimal solution.

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TABLE VII

c →		2	5	6	8	0	0	0	M	M	M	0
↓		x_1	x_2	x_3	x_4	s_1	s_2	s_3	t_1	t_2	t_3	r
M	t_1	4	$\frac{14}{3}$	$\frac{1}{3}$		-1		$\frac{2}{3}$	1		$-\frac{2}{3}$	$\frac{20}{3}$
M	t_2	1	$-\frac{7}{3}$	$\frac{16}{3}$			-1	$\frac{5}{3}$		1	$-\frac{5}{3}$	$\frac{2}{3}$
8	x_4		$\frac{2}{3}$	$\frac{1}{3}$	1			$-\frac{1}{3}$			$\frac{1}{3}$	$\frac{8}{3}$
z−c		5M −2	$\frac{7M}{3}$ $+\frac{1}{3}$	$\frac{17M}{3}$ $-\frac{10}{3}$		-M	-M	$\frac{7M}{3}$ $-\frac{8}{3}$			$-\frac{10M}{3}$ $+\frac{8}{3}$	$\frac{22M}{3}$ $+\frac{64}{3}$
M	t_1	$\frac{63}{16}$	$\frac{77}{16}$			-1	$\frac{1}{16}$	$\frac{9}{16}$	1	$-\frac{1}{16}$	$-\frac{9}{16}$	$\frac{53}{8}$
6	x_3	$\frac{3}{16}$	$-\frac{7}{16}$	1			$-\frac{3}{16}$	$\frac{5}{16}$		$\frac{3}{16}$	$-\frac{5}{16}$	$\frac{1}{8}$
8	x_4	$-\frac{1}{16}$	$\frac{13}{16}$		1		$\frac{1}{16}$	$-\frac{7}{16}$		$-\frac{1}{16}$	$\frac{7}{16}$	$\frac{21}{8}$
z−c		$\frac{63M}{16}$ $-\frac{11}{8}$	$\frac{77M}{16}$ $-\frac{9}{8}$			-M	$\frac{1M}{16}$ $-\frac{5}{8}$	$\frac{9M}{16}$ $-\frac{13}{8}$		$-\frac{17M}{16}$ $+\frac{5}{8}$	$-\frac{25M}{16}$ $+\frac{13}{8}$	$\frac{53M}{8}$ $+\frac{87}{4}$
5	x_2	$\frac{9}{11}$	1			$-\frac{16}{77}$	$\frac{1}{77}$	$\frac{9}{77}$	$\frac{16}{77}$	$-\frac{1}{77}$	$-\frac{9}{77}$	$\frac{106}{77}$
6	x_3	$\frac{6}{11}$		1		$\frac{1}{11}$	$-\frac{2}{11}$	$\frac{4}{11}$	$\frac{1}{11}$	$\frac{2}{11}$	$\frac{-4}{11}$	$\frac{8}{11}$
8	x_4	$-\frac{8}{11}$			1	$\frac{13}{77}$	$\frac{4}{77}$	$-\frac{41}{77}$	$-\frac{13}{77}$	$-\frac{4}{77}$	$\frac{41}{77}$	$\frac{116}{77}$
z−c		$-\frac{5}{11}$				$-\frac{18}{77}$	$-\frac{47}{77}$	$-\frac{115}{77}$	-M $+\frac{18}{77}$	-M $+\frac{44}{77}$	-M $+\frac{115}{77}$	$\frac{1794}{77}$

ESTABLISHING A QUALITY CONTROL PROGRAM IN THE PAPER MILL

Ralph E. Wareham and Maurice E. Blew
Quality Control Consultant and Strathmore Paper Company

Initiating the Quality Control Program

This paper is an attempt to answer some of the questions that arise when the management of a paper mill has made, or is about to make, the decision to establish a quality control program.

Mill management may have arrived at this decision either because of stimulation from within the organization or the incentive may have come from outside. In the first case, the person or persons doing the stimulating may have a formal program to propose; in the second case, the management must plan its own program.

A direct way to plan a program is to first set down the objectives. Where are we going? Which path shall we take to arrive there? Some of the objectives listed below are common to most paper mills:

1. Quality improvement
2. More product uniformity
3. Reduction of waste
4. Lower manufacturing costs

The selection of one of the above objectives fixes the goal toward which we are to work. Getting our feet on the right path toward this goal involves a description of QUALITY.

Improvements in product quality require that we have means to measure quality.

The desire to make a more uniform product must be fortified with the knowledge of present uniformity and how this reflects quality of the product.

Waste cannot be reduced until bad quality and good quality are clearly defined.

Cost reduction is important in mill operations but must be obtained without any lowering of quality.

Regardless of our objective, we are confronted from all sides by the term quality. Paper quality has three factors:

1. Chemical properties
2. Physical properties
3. Visual or appearance properties

The chemical and physical properties of paper are well known to all paper mill men and paper users. When important for use, requirements are clearly specified by the customer. On the other hand, the visual properties of paper have been more or less implied rather than specified. A consumer of paper is quick to notify the mill if holes, slugs or torn sheets are present in a delivery -- but rarely specifies this fact when ordering.

For these reasons, we must first select an objective and then define the required Quality properties of the product we manufacture. Next statistical methods can be used to measure the Quality properties of our product but for this we need persons trained in statistical quality control methods.

The selection and training of personnel may be said to be the first positive step in developing a quality control program. This is an area in which there is wide agreement among qualified persons. A young man from within the plant, possessing a degree in engineering with proved integrity and sound judgment, should be selected for training in statistical methods -- so that he may be the leader of a future quality control group. Lacking such a person within the organization, a man from Outside must be employed. Experience in many companies has shown that the first choice is to train a company man in statistical quality control methods, since this will bring more immediate benefits to the company, and smooth development of the program.

Information on training courses is readily available from local sections or from the National Headquarters of the American Society for Quality Control. The Society magazine, "Industrial Quality Control" publishes all necessary information pertaining to quality control courses offered by colleges and universities, or private organizations. There are suitable avenues for training throughout the United States and Canada.

In planning and developing the quality control program, the services of a consultant should be considered. Management should give a newly trained quality control man the benefit of advice and consulting services when they are needed. Consultants can give aid in planning and appraising a program and quite often may mean the difference between the success or failure of a quality control program. Here again I.Q.C. offers valuable information and assistance in selecting a consultant. Approved consultants have the privilege of advertising their services in the pages of the "Industrial Quality Control" magazine.

Inspection Audit

An inspection audit is many things: first, it is a statement of quality in terms of fraction defective, percent defective, or number of defects per unit; secondly, it is a statement of quality in terms of acceptable quality level. The level may be acceptable, marginal, or not acceptable. In paper making terms, fraction defective may be thought of as the ratio of defective sheets of paper to the total number of sheets in a unit. The number of defects may be associated with roll stock and reported as number of defects per "X" linear feet or "X" pounds of paper. To be completely understood by all persons concerned, defects should be classified according to their importance to the consumer.

CRITICAL DEFECTS, such as slugs, holes, and folded sheets, will most certainly cause damage to printing or converting equipment.

MAJOR DEFECTS, such as wrinkles and blemishes, will make the paper unusable.

MINOR DEFECTS, such as small and infrequent blemishes which are

not conspicuous enough to make the paper unusable but nevertheless are easily recognized as being lower in quality.

This part of the audit is obtained by inspecting finished packages of paper with the aid of sampling procedures. When completed and in report form, the audit will show the outgoing quality of the product with respect to visual or appearance factors. The remaining part of the audit is concerned with the chemical and physical factors of the product. Information on these factors are usually available from laboratory records and need only to be analyzed by statistical methods. Such an analysis will answer the following questions: Are chemical and physical specifications complied with 100% of the time?

When chemical and physical specifications are not complied with, is the product acceptable? Is the product of marginal value? Is the product unacceptable?

When completed, the QUALITY AUDIT may be in the following form:

VISUAL DEFECTS	Critical Defects	0.05%
	Major Defects	1.00%
	Minor Defects	4.00%
CHEMICAL PROPERTIES	80% of the product meets specifications.	
PHYSICAL PROPERTIES	70% of the product meets specifications.	

The original purpose of the audit is now evident. Our problems are pinpointed and our program may now be directed to the specific problems posed by the quality audit.

Selecting Control Points

The job of selecting control points is a key step in developing a quality control program. The control points must be set at positions where a decision can be made as to whether to accept or reject the product. They must be set at positions where the process may be changed either to raise or lower a specific quality factor.

In order to decide where the control points are to be located, it is advantageous to make use of the information supplied by the inspection audit. Each item of the audit is analyzed as to its effect on the customer or on costs. For example, the presence of .05% critical defects is at the frequency of one critical defect for each two thousand sheets of paper. Quality of this description is, of course, impossible to live with for any length of time; it places the very existence of the mill in jeopardy. Further analysis is unnecessary because we know that this paper is unusable in any modern print shop.

Working with these facts, we can select the control points for the plant. In the case of critical defects, the problem is to eliminate or greatly reduce the incidence of these defects. The words eliminate and reduce are used guardedly because it may be possible to reduce these defects to 1 per 100,000 with only a small added expense, whereas the complete elimination may involve major changes in machinery or production methods.

In the course of developing a quality control program at Strathmore Paper Company, control points have been established at the following steps in manufacturing operations:

Purchased wood pulp
Purchased cotton fiber
Sorting of cotton fiber
Cutting of cotton cloth
Cooking of cotton cuttings
Washing and bleaching of cotton cuttings
Control of beating
Control of jordans
Technical control on paper machines
Visual quality on paper machines
Control of sizing and air drying
Sheeter control
Control of inspection and counting

In addition to the above, special studies have been made at other key points in the manufacturing process.

Setting Quality Standards

In evaluating quality at the selected control points, accurate quality standards are needed. Such standards must be economically sound to the extent that the manufacturing process must be capable of producing paper that will meet the standard; the standard must meet customer requirements as well.

The Quality Control Engineer is in a good position to prepare and recommend quality standards for the various company products. However, the approval and acceptance of quality standards must be a joint approval concurred in by sales, production, and the technical staff. To spell this idea out more plainly, no one person should assume or have delegated to him sole responsibility for the final quality of company products.

Process standards may be a part of product standards but do not need to be as rigid in being approved. The Production Department being provided with product standards may have a certain amount of freedom or latitude in processing just so long as the final standards are met. Nevertheless, all standards must be in writing, clearly written in language that all can understand.

Quality Mindedness

At this point, it is well to pause and reflect on a few simple truths. Quality is built into the product. Inspection or testing does not raise the quality of a product. In the paper industry, it is more economical to produce a high quality product and market it with a minimum of inspection and sorting, then it is to make a low quality product that requires a maximum of inspection and sorting.

These statements lead us to the most important part of any quality control program: the attitude of management and the attitude of all employees toward quality. QUALITY MINDEDNESS is the phrase most often used to refer to this attitude or state of mind. The desire for

quality must be carefully nurtured and promoted at all levels of operation. Purchasing agents in their desire to buy low must be fully aware of the risk involved when they buy too low.

Production personnel are involved with risks when they are faced with the problem of using marginal raw materials. Other risks are associated with maintenance of machinery and equipment, and with careless or negligent employees.

QUALITY MINDEDNESS is best nurtured and encouraged with the spoken word through the medium of group meetings. Small groups may meet on a bi-weekly or monthly basis and larger groups on a semi-annual or annual basis. These meetings are essentially progress reports demonstrating and illustrating the quality of work done by a particular group or department. Poster and Slogan contests are useful in a limited way, to emphasize a point or to provide stimulation for a short period of time.

Control of Outgoing Product Quality

The inspection audit performed earlier in the program may form the basis for control of Outgoing Product Quality. In any case, checks are needed to confirm or reject data established by process control results. We say in effect that, if our product passes the standards set up at the different parts of the process, the final product will be of good acceptable quality. We must first prove that our process standards are realistic and accurate. Having proved this to every one's satisfaction, final inspection can then be geared to the quality of work performed. The inspection may be light, normal, or tightened as the situation demands.

Reports to Management

When planning and preparing reports, all levels of management must be considered. Foreman and supervisors are very important parts of the management function and require frequent and detailed reports of the operations they are most concerned with. In most cases, a monthly summary report is adequate for the higher levels of management.

Summary

The program outlined in this paper is designed to control the quality of a manufactured product such as paper and is directed at the purchasing, manufacturing, and inspection operations.

In our development of Quality Control at Strathmore Paper Company, the first year was spent in developing quality control for one mill only. Then the program was extended to other mills of the company. At the end of the third year, we had approved process standards covering all products and all operations. Sometime during the fifth year, we considered ourselves to be a smoothly functioning group operating at a peak of efficiency.

Our experience would bear out the old saying that "Rome was not built in a day."

ENGINE MANUFACTURING AND FOUNDRY OPERATIONS

Irwin A. De Grote
Engine and Foundry Division
Ford Motor Company

Ten years ago, when our Quality Control Society was formed, it was relatively easy for a speaker on S. Q. C. to interest his audience. There were then many new concepts and ideas to be discussed, and almost any case study was novel and interesting to us. Today's danger, with all that has been said and written in the intervening years, lies in the possibility of tedious repetition.

To avoid that, we have decided to stay close to home and to talk only of those things with which we have been recently associated at Ford. We will discuss mainly machine capability tests and special case studies which we trust will prove both interesting and helpful. Before going into these, though, a brief synopsis of our organization might be in order.

There are seven major plants in our division, responsible for the manufacture of the Ford, Mercury, Thunderbird, Lincoln, and Continental engines. Each has its own Quality Control Manager and Quality Analysis Section. The Analysis Section is composed of analysts, illustrators, and special inspectors. Each analyst is assigned to control a certain group of parts and to make any special studies required in his area. The illustrators prepare the charts for the analysts and the floor inspectors plot the control charts on the floor. The special inspectors are reserved to work with the Quality Analysts in making special studies.

Operationally, we are concerned with five basic aspects of statistical quality control.

1. Receiving inspection.
2. Outgoing sampling and testing.
3. In process controls.
4. Machine capability studies.
5. Special case studies or trouble shooting.

Receiving Inspection

In receiving inspection instruction sheets are written and filed with the blue print. These instruction sheets show:

a. The characteristics to be checked.
b. The acceptable quality level.
c. The designation of the defects as critical, major, or minor and
d. The gages to be used in checking the parts.

A card file is maintained on each part showing the lot size, sample size, number of defects found, and the process average. We use an adaptation of the Joint Army-Navy Tables (Jan. Std. 105).

Outgoing Sampling and Testing

1. Some parts are inspected 100%.

2. Some assemblies, such as oil pumps, are 100% functionally tested.

3. Every engine is "hot" tested under its own power.

4. Engines are selected at random and given durability tests and oil consumption tests.

5. Other engines are selected at random daily, disassembled and parts checked to see that they meet specifications.

These results, from all engine plants, are reported in histogram form by our Division Staff Analysis Section.

We also do some sampling of small parts which are made in our plants and shipped to others--either within the division or to other divisions.

We much prefer satisfactory "in process" controls, though, to sampling the outgoing product.

"In Process" Controls

By "in process" controls, we mean mainly $\bar{X}$ and R charts. These have been referred to as "bread and butter" controls by Dr. Martin Brumbaugh, who was the 1951 Shewhart Medalist and the founder of our magazine, "Industrial Quality Control".

We have, in our division, over 2,000 charts, but we are not impressed with numbers--the important factors are:

How many are being used as they are intended?

Do you look for an assignable cause when a point goes out of control?

Does somebody take corrective action?

Dr. Joseph Juran, another well known authority in the field of quality control, reminds us of one of the factors in successful programs: "There must be recognition of the fact that the basic objective is prevention of defects, and that all else is secondary."(1) It is well to remember this--if you prevent the making of defectives, you won't need to sample the outgoing product--it will be satisfactory. You won't need to 100% inspect the product--because it will be better than any sorting operation could guarantee.

Machine Capability Studies

The next phase--Machine Capability Studies--goes hand in hand with "in process" controls. Before you can prevent the making of defectives in any process--even with statistical controls--that process must be capable of making the parts within the specification.

There are numerous and varied opinions as to the correct method of making machine capability studies. I believe though, that all of us here, at least, can agree it must be based on statistical methods.

We, in the Engine and Foundry Division, use an approach which we feel is sound. It is about as simple as we know how to make it and still take advantage of the probability theory, which is the foundation of all S. Q. C. All we use is plain, simple arithmetic, thanks to Dr. Shewhart and other pioneers in the field.

Before proceeding, there must be an answer to an important question.

What amount of total tolerance should reasonably be allowed to the machine, and what amount reserved for unavoidable external factors in production?

Machine processes differ greatly in nature, and a flat, across-the-board standard allowance is not possible. Each case must be decided on its own set of circumstances.

It is Ford's experience in production, however, that jobs presently successful from the quality standpoint are generally those in which basic machine variation consumes no more than 3/4 of specification tolerance. This approach does not deprive the machine builder of any part of total specified tolerance. It does not require him to provide a machine which is in any degree more precise than it should be. But it does enable him to judge by actual trial whether the machine is likely to be adequate, quality-wise, for the production operation it was designed to perform. It would be found, in fact, that any machine now making quality parts in production has basic variation, which can meet such tests of capability. On the other hand, those which would fail such tests, presently result in high scrap and rework costs.

We divide machines or processes into two types:

1. Adjustable and
2. Non-adjustable.

An adjustable machine or process is one in which the average dimension can be changed by the operator or job setter in a reasonably short time. For example, turning the diameter of a shaft, cutting piston pins to length, or boring a hole to a certain size. If the average is readily adjustable, all we need to know is the expected variation.

A non-adjustable machine or process is one in which the average cannot be readily changed, except by machine repair or maintenance personnel. This might include off-squareness of a bore to its locating face or the center distance between two holes drilled or reamed simultaneously. You can readily see that in these cases, we must consider not only the expected variation, but also the average from which this variation is to be expected.

For example, if you know my range in bowling is 35 and you know that Ned Day's is 35--does that mean we are equally capable--certainly not? He may vary around a 205 average, while I may vary around 160 average--the only similarity is in our variation, not our capability. And as far as I'm concerned, mine is a non-adjustable process--at least I would require "reworking" by experts to bring my average up to 205.

Briefly, this is what we advocate to make the capability study:

1. Have the process man check the cycling, speeds, feeds, tools, etc.

2. Then run (without adjusting, if possible) a minimum of 50 consecutive* pieces. We prefer 125, if this is feasible.

3. Plot a $\bar{X}$ and R chart in samples of 5 (other sample sizes may be used).

4. Apply statistical limits to the $\bar{X}$ and R charts.

5. If the process shows a "state of control", calculate the capability of:

   a. An adjustable machine or process by the first formula in the right hand corner of the chart in Figure 1.

$$= 2K\bar{R}$$

$$= 2(1.289)(.0023") = .0059"$$

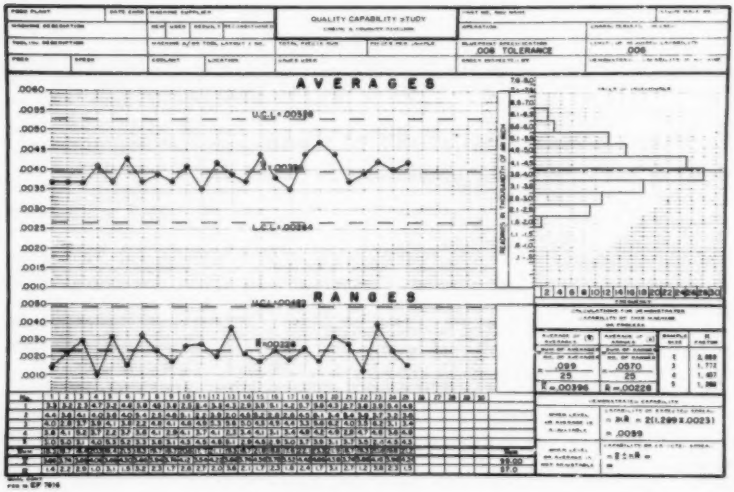


Figure 1. Quality Capability Study Chart

If the part tolerance is .008", the machine is capable since .0059" does not exceed .006", which is 3/4 of part tolerance.

   b. Using the same data, the "short run capability" of a non-adjustable process is found by the second formula in the lower right hand corner.

* Capability can be determined, even though all are not consecutive, as long as the pieces in <u>each sample</u> are consecutive.

$$\bar{\bar{X}} \pm K\bar{R}$$

$$\text{or } .00396 \pm (1.289)(.0023)$$

$$= .00396 \pm .00296$$

$$= .0010\text{"to } .0069\text{"}$$

If the part tolerance is .008", this machine is not capable (for the "long run") since .0069" exceeds .006", which is 3/4 of part tolerance.

If at all possible, the tests should be made on the machine builder's floor. There are good reasons for this:

First, because the builder will then have a record to show that the machine was capable before leaving his plant.

Secondly, because any corrections that are required can be made in his plant where he has the right equipment and can, therefore, do the job more easily and at lower cost to him.

Third, because it will save him money on the expense of service men, who may spend weeks or even months in the purchaser's plant, trying to correct something, with inadequate facillities or time limitations, that could have been prevented by a few hours work in the builder's plant.

The advantages to us, the purchaser, are obvious:

1. Better quality.

2. The elimination of "bottleneck" operations due to inability of the machine to produce parts within tolerance.

Another facet of capability studies is the assistance to manufacturing engineering in determining which of two or more processes produces the best quality part. This would include the type, design, and make of machine, as well as the best sequence of operations. You might be asked, as we were, "Is it better to rough and finish bore the cylinder block in the same operation or is it better to rough bore, complete the other operations, and then finish bore?" This is the type of information we compile to report to the manufacturing engineering section. They then use these statistical facts and proof, along with experience and other factors, as a basis for decisions.

Special Studies

Special studies are those where we are attempting to solve a quality, scrap, or rework problem when there are so many variables involved that the foreman (who is being blamed for failure to solve it) can't possibly be expected to find the answer. Even if he were trained in the statistical methods approach, he could not spend the time and effort necessary to find the solution.

This, I feel, is one of our prime responsibilities--to help the foreman produce better quality parts more easily. We feel that the

analyst's job is not completed when he puts up a chart and merely hopes for the best or says, "This job isn't satisfactory--fix it!"

We prefer, if we find after putting up the charts that the process isn't capable of meeting the specification, to make a special study. We then:

1. Point out what is wrong--if we can find out.

2. Recommend what should be done to fix it--if we know. (Notice we tell him what should be done, not how!)

3. Follow up to see that it is fixed and

4. Restudy--to see whether the "fix" was satisfactory, then

5. Continue chart control to see that the "fix" is permanent.

Some of you may feel that this is going "beyond the call of duty" or trodding on the toes of maintenance, machine repair, or production to tell them what should be done. We do this only when we feel he has no way of knowing what is required. It is much easier to get action on a specific request than a generalization of a problem.

For example, we had an eight station machine which we had studied and we showed the foreman our chart and suggested that he move two of the fixtures into line with the other six. By being specific, we were able to get corrective action quickly. This job saved the company $100,000 in one year.

Valve Stem Clearances

Another special study was the fitting of the valve stem in the valve guide hole of the cylinder head. Valve stem dianeters and valve guide hole diameters were manufactured to a .001 total tolerance for each. They were then gaged and separated into two groups of .0005" each. The smaller ones were identified by a red mark and the larger ones by a green mark. Red valves were then assembled into red holes and green valves into green holes.

This would seem to be a good system to guarantee the maintenance of close tolerances on clearance. There are several reasons why this doesn't work as perfectly as one might assume:

1. The assembler can make a mistake and put the wrong color valve in the hole.

2. The person color coding valve holes can err in marking the color next to the hole.

3. The quantities of red valves and red holes seldom balance.

4. Any error in gaging--even one ten-thousandths of an inch can result in exceeding the clearance tolerances.

We decided that we might be able to eliminate color coding and do an even better job. First, we checked to see what clearances we would

have if we disregarded color codes and assembled the valves at random (Figure 2).

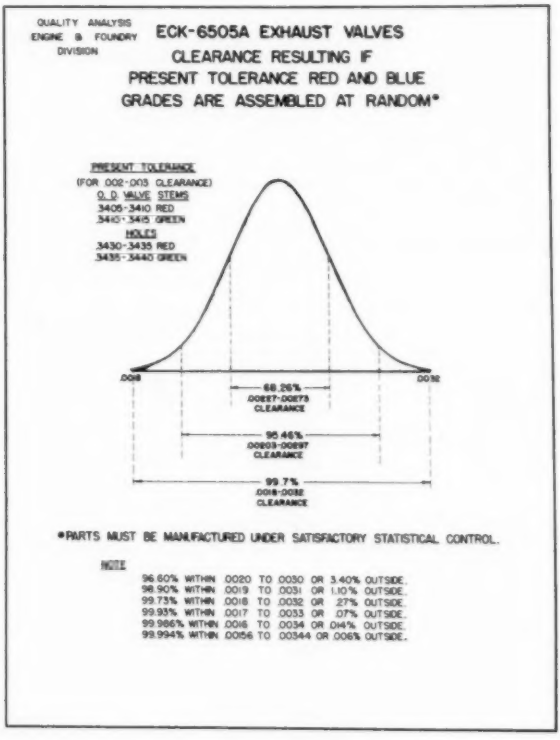


Figure 2.

You can see that we could not permit the assembly of parts with these tolerances because 3.4% would be outside of the clearance limits. The question then, was what tolerance must we hold on both valves and holes in order to eliminate color coding and assemble any valve in any hole at random?

Instead of the usual procedure of taking the standard deviation of each of the parts and calculating the clearances to be expected, we reversed the procedure. The spread of clearance we want is .001" and this is the spread of each part tolerance--this means we can't leave one alone and reduce the other because the spread would have to be zero on one in order for the clearance spread to be .001. The least reduction would be to reduce both the same amount.

Engineers, who are not familiar with the statistical approach to assembly tolerances, always take the smallest diameter valve and subtract it from the largest hole (and vice versa) to find out what

clearances to expect. You could not expect them to do otherwise before S. Q. C. was developed and you cannot expect them to do otherwise now unless they understand statistical methods or you can satisfactorily explain to them why they can rely on this new concept.

Actually, the formula is simple. Most of you here are very familiar with it, but for the benefit of the few who may not be, let's look at it for a moment. If you know how to find the hypotenuse of a right triangle, when the two sides are given, you already know the basic formula for the assembly of two parts.

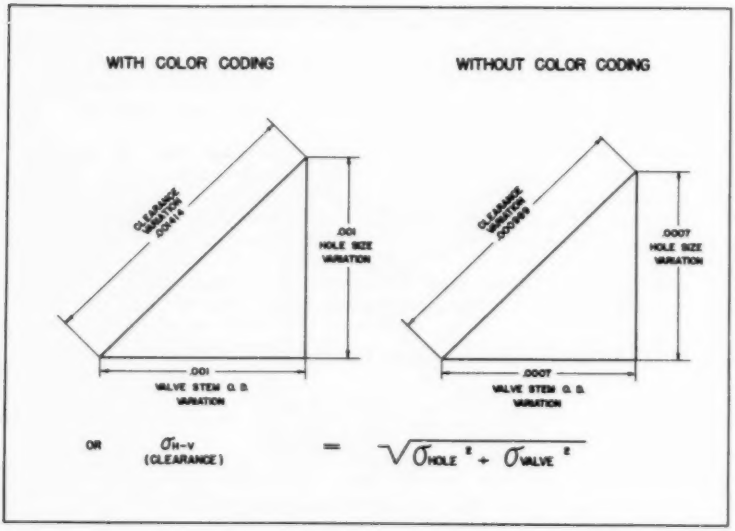


Figure 3.

Actually, what we are saying is that the extremes rarely (if ever) will be assembled together, consequently the spread is not the sum of the parts spread (or variation) but something less. The probability of occurrence can be calculated so that the risk is at a minimum.

We want to hold .001" total spread for clearance and by using the above formula, we found the following:

Both Part Tolerances	σ_{H-V}	Expected Spread of Clearances
.0008	.000188	.001128
(.0007)	(.000165)	(.000989)
.0006	.000141	.000846

A tolerance of .0008" on each part would have permitted too much variation in clearances (.001128). Tolerances of .0006" would have given us better assurance of being 100% within tolerance, but we felt

that for the little to be gained, it was not good judgement to reduce the tolerance to .0006" rather than .0007". We decided on .0007" for both the valve stem diameter and the hole size.

The next step was to see whether or not we were capable of holding this tolerance economically. This was a relatively simple matter for the valve guide holes of the cylinder heads because we maintain statistical control charts on each line.

The valve stem diameters was another matter since our division doesn't machine the valves. Some are machined by another division of the company and some by an outside source. They had a few qualms about it, but agreed to try to produce them within the .0007" spread.

These charts (Figure 4) were discussed with the engineering department personnel, who agreed to a trial run.

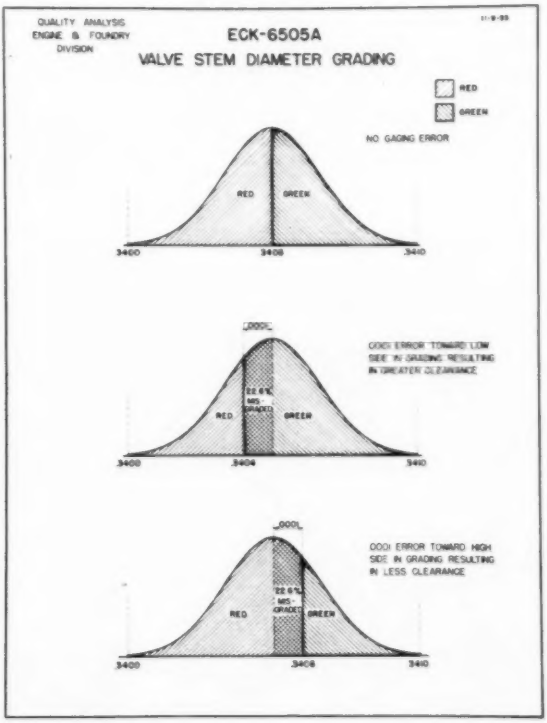


Figure 4.

You can see from the top distribution that we were asking the inspector to cut this distribution in half and call one group red, the other green. The only fallacy is, that when you try to gage parts within a ten-thousandth of an inch, you can easily make an error of that

much due to:

1. Temperature variation between parts.

2. Error in setting up the gage.

3. Inspector errors.

Notice that if only a one-tenth (.0001") error is made, it affects 22.6% of the parts at the center of the distribution and 1.5% at the tail (latter not shown). This is in addition to any errors in assembling or marking the wrong valve guide hole. These errors can occur on either the holes or valves.

Assuming we continue to make this one-tenth error with the new tolerance, but no color coding, we minimize the error because only the tail of the distribution (1.5%) is affected (Figure 5).

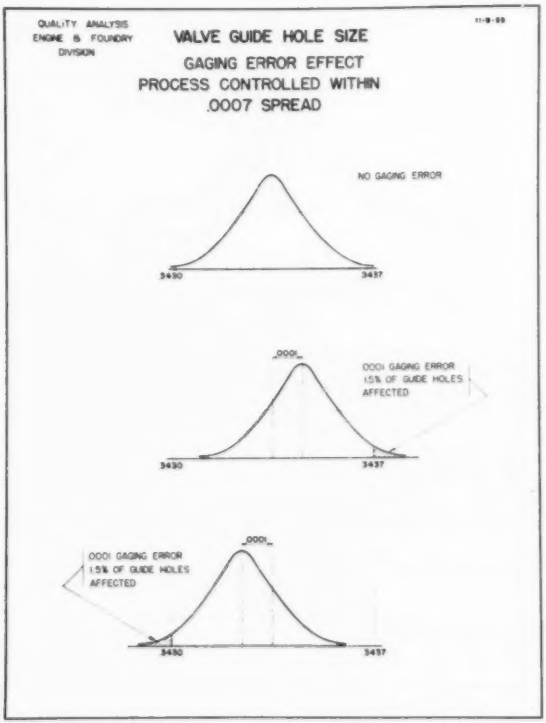


Figure 5.

We have now discontinued color coding valves and holes and, besides saving money, have better assurance of trouble free performance.

Intake Manifold

Engineering had found a certain degree of mismatch between the port openings of the intake manifold and those in the cylinder head. They felt this should be corrected to increase horsepower. We were requested to make a study and obtain corrective action. If the edge of the cylinder head port extends into the manifold port, it will cause turbulence of the gasoline vapors as they travel from the carburetor through the intake manifold into the combustion chamber. If the manifold opening overlaps the head port, it causes a restriction by reducing the area of the opening. This is considered the lesser of the two evils.

This was a somewhat different problem in that the eight port openings had to be matched on all four sides with the eight openings in the head. The question was whether the trouble was in the machining, the patterns, or core shift.

1. The manifolds were milled and drilled on a multiple station machine.

2. There were variations in the castings.

We used a gage, which simulates the head, that has "windows" representing the port openings. By using a scale graduated in hundredths of an inch and interpolating, we could measure the mismatch within a few thousandths (Figure 6).

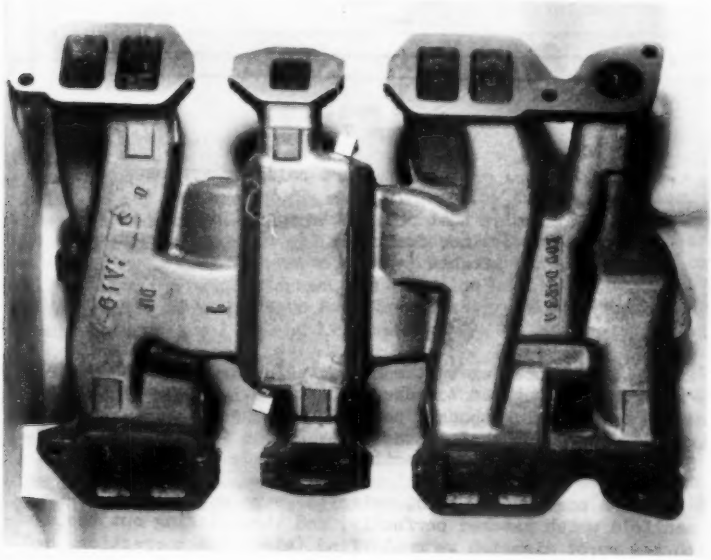


Figure 6.

We used the average of 25 castings and the results are shown in Figure 7.

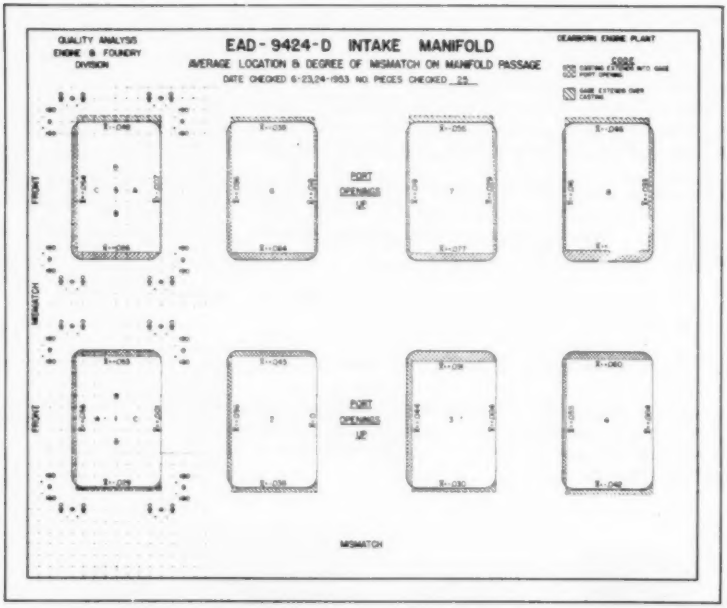


Figure 7.

We try to use a more or less standard coloring system:

Blue — for those that are within specifications.
Yellow — for not too desirable (double cross-hatch).
Red — for undesirable (single cross-hatch).

Consequently, we show the restriction as yellow and the turbulence as red.

I explained the problem to the manager of our pattern shop, gave him the chart, and he agreed to make corrections. He understands and believes in Statistical Methods*, consequently, he agreed to the corrections instead of arguing that it was probably the fault of machining. Figure 8 shows the job after corrections were made.

We then ran horsepower tests, using the same engine. First, running a manifold which matched perfectly, and then picking out the manifold with the worst mismatch we could find (since the corrections had been made). We found that we had accomplished our purpose--there was no

* Ford has a training program for all supervisory personnel which includes Statistics and Statistical Quality Control Courses.

appreciable difference.

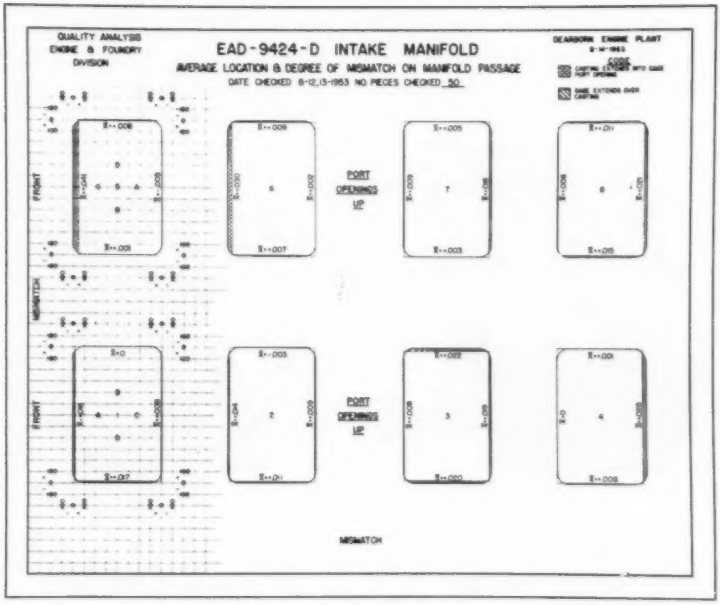


Figure 8.

Cylinder Head

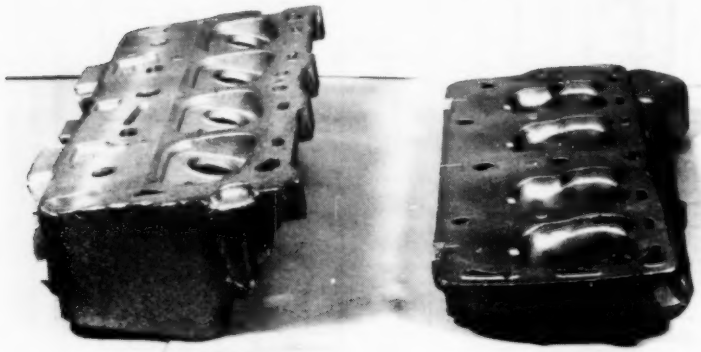
This, to me, was one of the more interesting foundry examples, where we found the answer to a problem through a $\bar{X}$ and R chart. In our old "L" head engine, warp of cylinder heads had always been troublesome from a machining standpoint, since combustion chamber volume must be controlled. (Our present overhead valve engine head has a much heavier section and there is no problem in this respect.) Figure 9 shows the difference between the 1951 and 1956 heads.

Both foundry and machining personnel were aware of this condition and so purposely machined the heads so that the end chambers were toward the maximum specification for volume and the center ones toward the minimum. $\bar{X}$ and R charts were used for control.

Efforts to reduce warp in the foundry were being made constantly, but were directed toward different methods of gating, positioning in the mold, etc.

A remodeling change was made in the foundry causing certain parts to be shifted to other lines. The equipment on this new line was similar in nearly all respects to the old line. The length of the line (affecting technique and cooling time) was identical to the old. The

metal came the same distance to the pouring station from the same cupola. No changes in analysis or temperature were made.



1956 CYLINDER HEAD

1951 CYLINDER HEAD

Figure 9.

Control charts ($\bar{X}$ and R) had been plotted on cylinder head warp for some time. Five heads were checked hourly and plotted on the chart. When the head job was transferred to the new line, the control chart was transferred too.

It was noted immediately that the head warp was materially affected by the change. From a previous plus (+) condition, the warp now tended to be minus (-) or bowed down in the mold. This meant an assignable cause, which at first glance appeared to be an inspector error--but was not. The Quality Control analyst started investigating. He found but one difference between conditions on the old and new lines. That difference was in the type of bonding agent used. On the old line, Western Bentonite was used 100% as the bonding agent. On the new line, a fire clay, called Revivo, was being used 100%. Histograms were presented to management. The plant manager suggested, as you might guess, a combination of the two bonding agents. Figure 10 shows the results from each bonding agent and the improvement after mixing the two.

Metal Analysis and Sand Control

In the foundries, we use $\bar{X}$ and R charts:

For Metal Analysis Control:

1. Pouring temperatures.

2. Silicon
3. Carbon
4. Blast rate.

For Sand Control:

1. Moisture content.
2. Permeability.
3. Bond--or green strength.

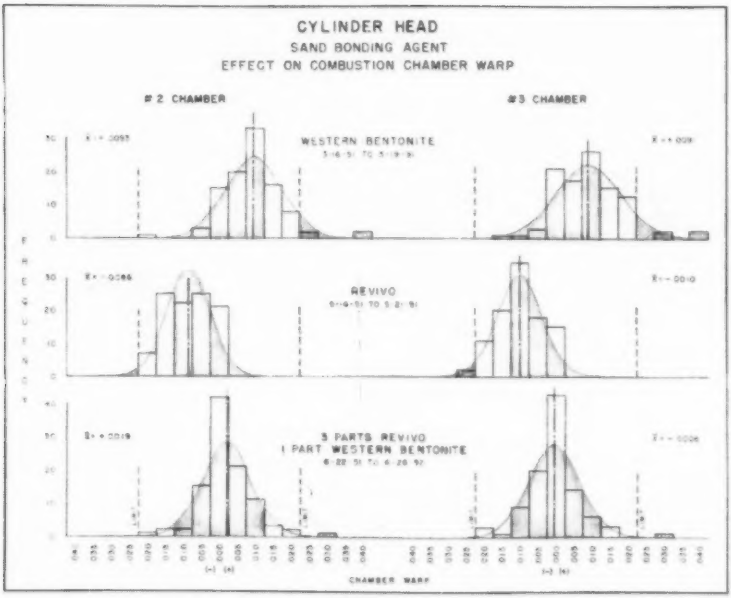


Figure 10.

A great deal of work has also been done in our foundries by S. Q. C. methods in reducing the amount of stock on castings to increase broach life and in solving many other problems involving variables in foundry operations.

Piston Inventory

Piston fitting is a simple matter since all cylinder bores and pistons are graded and numbered. It is merely a matter of putting a #6 piston into a #6 bore. We have eight grades--each grade having a spread of .0003". In other words, the total tolerance for all eight grades is less than the thickness of a piece of writing paper.

Both the block department and the piston department could run within the eight grades specified, but as you might guess, the distributions of the two departments did not coincide. The problem, prior to S. Q. C., was to have the right quantity of each size of piston when needed.

The assembly department would call for #8 pistons to fit the corresponding bores. Later, the piston department would discover that they

had too many #8 pistons and would ask the block department to hone some #8 bores.

This was the solution:

1. We used $\bar{X}$ and R charts to control both the block bores and the piston with limits calculated from the desired mean.

2. We requested a change in conveyor distribution.

   a. It had been a rectangular distribution--an equal quantity of hooks for each size.

   b. This was changed to a more normal distribution similar to Figure 11.

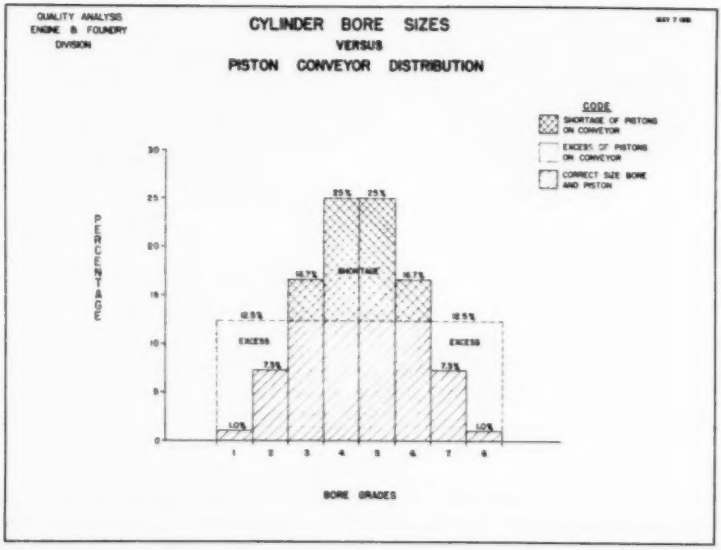


Figure 11.

3. We now attempt to control the inventory according to the normal distribution (Figure 12).

Prior to S. Q. C., in order for us to have a three day supply of #4's and #5's, we had a 75 day supply of #1's and #8's!

We can now have the correct supply with just half the inventory. Where we needed 160,000 for one day, we now need only 80,000 for the same production. It is particularly helpful to production control at the end of a model run in "balancing out".

QUALITY ANALYSIS
ENGINE & FOUNDRY
DIVISION

FEBRUARY 23, 1954

PISTON INVENTORY

PISTON NO.	OLD DISTRIBUTION	SUPPLY	NEW DISTRIBUTION		SUPPLY
1	20,000	25 DAYS	800	1.0%	1 DAY
2	20,000	3.4 DAYS	5,840	7.3%	1 DAY
3	20,000	1.5 DAYS	13,360	16.7%	1 DAY
4	20,000	1 DAY	20,000	25.0%	1 DAY
5	20,000	1 DAY	20,000	25.0%	1 DAY
6	20,000	1.5 DAYS	13,360	16.7%	1 DAY
7	20,000	3.4 DAYS	5,840	7.3%	1 DAY
8	20,000	25 DAYS	800	1.0%	1 DAY
	160,000		80,000	100.0%	

Figure 12.

Connecting Rod "Bend and Twist"

A problem that is common to the entire automotive industry is what is known as "bend and twist" of connecting rods. One of our more complicated studies was made to solve this problem. The explanation of our solution, however, would take this entire period, so I will merely tell you that there were several "side benefits":

1. Oversize bores were cut 25%.

2. Undersize pin holes were reduced 44%.

3. Pin holes--not cleaned up--were cut in half.

4. Scrap was reduced 44%.

5. Savings on scrap alone were $129,000 a year.

We, in Quality Control, should blame no one but ourselves if our programs do not succeed. We should assume that if foremen do not believe in S. Q. C. or if our management is reluctant to back our programs, it is because we have failed.

The General Manager of the Engine and Foundry Division, Charles H. Patterson, talking on "What Management Expects of Quality Control", expressed it this way, "I am suggesting that you look realistically at your inheritance. The burden of proof rests with you. Where you meet disbelief, you must present the facts and where you meet reluctance, you must counter with action. It will not do merely to hang a control chart

on the wall and to draw jagged lines across it. You could have a thousand such charts and not prove it to me. You could show me statistics enumerating the number of certification agreements you have in effect, you could roll your dice and prove your probability theories; but, I will still look at the car coming off the end of the line to judge if you are worth your salt."

References

1. Juran, J. M., "Insure Success for Your Quality Control Program" Factory Management and Maintenance, Vol. 108, No. 10, 106-109, October 1950.

2. Grant, E. L., Statistical Quality Control, McGraw-Hill Co., Inc., New York.

3. Patterson, Charles H., "What Management Expects of Quality Control", address given at Rackham Building, Detroit, Michigan, January 15, 1954.

NONRANDOM DISTRIBUTION OF VARIABLES
ROCKWELL HARDNESSES OF HOT ROLLED STEEL SHEETS IN COIL FORM

John W. W. Sullivan
American Iron and Steel Institute

Sampling of Coils. At the Sixth Annual Convention of this Society, I inquired, "How can a coil be sampled without producing two or more coils?" (1) That question remains unanswered. However, the case history to be examined this morning may increase our understanding of the nature of the problem of evaluating the quality of continuously extended product, such as hot rolled steel sheets in coil form.

Some purchasers of steel require delivery of the product in coils because their fabrication methods necessitate the use of coils rather than individual sheets. Consequently, destructive testing can be performed only on the ends of such coils.

In the following case history, the results of hardness tests on the ends of each of five coils are compared with test results on about one-third of the 60 sheets into which each coil was cut. In addition, the hardness distributions throughout the coils, as shown by tests on the sheets, and the hardness distributions across the coil width are examined in relation to manufacturing variables.

The five coils comprising this case history are described in Exhibit A, along with significant data on manufacturing practices. Those data show that the coils were made from the same heat of rimmed steel and were rolled under conditions that are as nearly identical as can be obtained in steel mill operation. Care was exercised in selecting the coils so that they represent probably the most uniform steelmaking practices and processing operations to be expected in the production of such material.

Each coil weighed about 17,000 lbs. and was sheared into approximately 60 sheets. On every third sheet, four Rockwell B hardness measurements (very closely adjacent) were made at each of three locations, namely, 1-1/2 inches from the band edge, 12 inches from the band edge, and at the center of the sheet. The tested sheets are numbered 1 to 20 from head to tail of the coil.

Comparison of end sheets with remaining sheets in coil.

Hardness data on the end sheets of Coil A are summarized in Table 1.

Table 1

Rockwell B Hardness Data - Coil A

Sheet No.	Location of Hardness Tests					
	1-1/2 in. from band edge		12 in. from band edge		Center	
	Ave.[a]	Range	Ave.[a]	Range	Ave.[a]	Range
1 (Head)	19.3	1.5	13.0	1.5	15.1	2.5
20 (Tail)	12.3	1.5	17.9	2.5	18.5	1.0

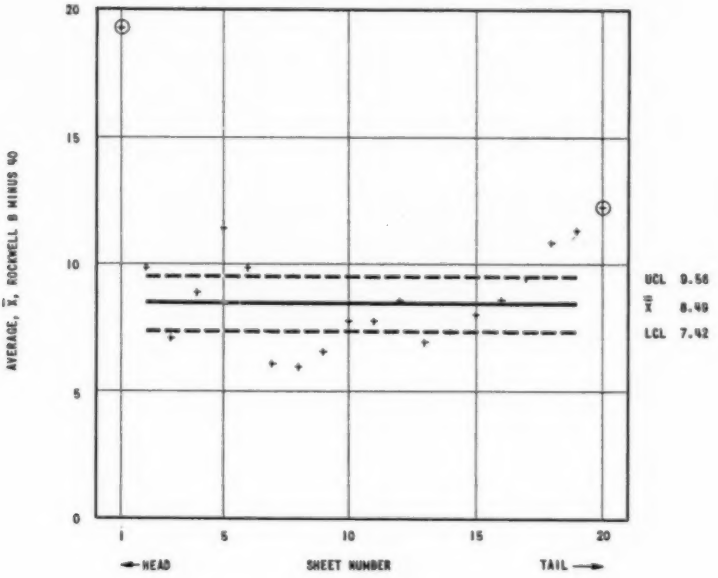
[a] To facilitate computation 40 was subtracted from each Rockwell B reading.

Let us assume that no data are available on hardness distribution throughout coils manufactured essentially the same as Coil A. In that event, the hardness data on the end sheets cannot be used to evaluate hardness throughout the coil because we have no information to enable us to relate the hardness of the end sheets with the hardness of the remaining sheets.

Actually, the end sheet data are higher than the upper control limit[b] for average, at three locations, for the remaining 18 sheets in Coil A, as shown in Figures 1, 2, and 3.

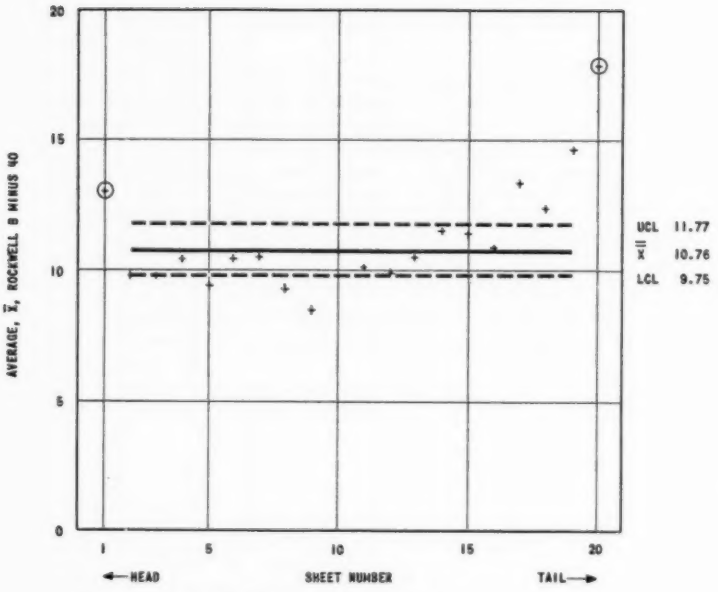
[b] Control limits for average and range were computed by means of Table II Factors for Computing Control Chart Lines--No Standard Given (2).

FIGURE 1 - Control Chart for Average, $\overline{X}$
Coil A, 1-1/2 Inch from Band Edge



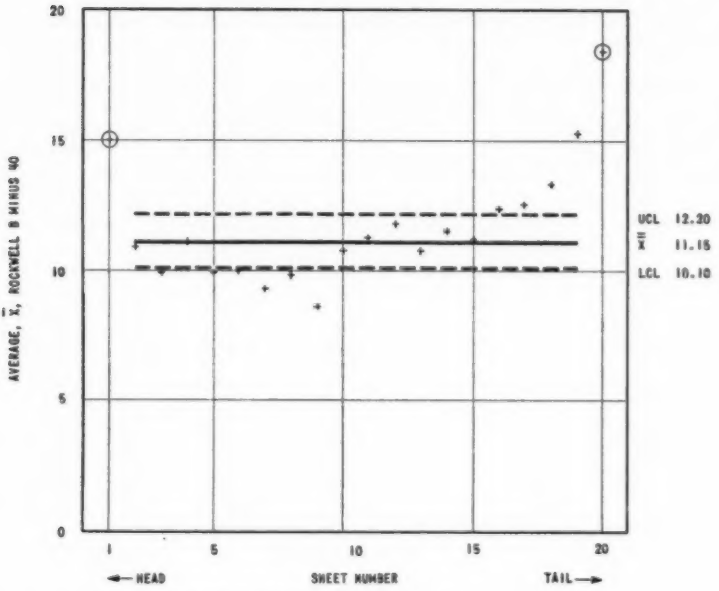
NOTE: Points for head and tail sheets are circled.

FIGURE 2 - Control Chart for Average, $\bar{X}$
Coil A, 12 Inches from Band Edge



NOTE: Points for head and tail sheets are circled.

FIGURE 3 - Control Chart for Average, $\bar{X}$
Coil A, Center of Sheet



NOTE: Points for head and tail sheets are circled.

The hardness data for the end sheets are encircled.

Even with the hardness data available on Sheets 2 to 19, inclusive, the hardness data on the end sheets cannot be used to evaluate the hardness of Coil A in the absence of such other information as the manufacturing controls used in producing Coil A.

Similarly, the data on the end sheets of the other coils cannot be used to evaluate the hardness of the coils. For convenience, the end sheet data for five coils, A to E, and the control limits for Average and Range of the remaining 18 sheets are listed in Table 2. End sheet values outside the control limits for average are underlined.

Table 2

Comparison of Rockwell B hardness average of end sheets (1, Head and 20, Tail) with control limits for average of the remaining 18 sheets (2 to 19, inclusive), for three locations across the sheet for each of five coils, A to E, inclusive.

Sheet No.	Location of Hardness Tests					
	1-1/2 in. from band edge		12 in. from band edge		Center	
	Ave.[a]	Range	Ave.[a]	Range	Ave.[a]	Range
Coil A						
Head 1	19.3	1.5	13.0	1.5	15.1	2.5
UCL 2-19	9.6	3.4	11.8	3.2	12.2	3.3
LCL 2-19	7.4	0	9.8	0	10.1	0
Tail 20	12.3	1.5	17.9	2.5	18.5	1.0
Coil B						
Head 1	17.4	3.5	10.9	1.5	12.1	2.0
UCL 2-19	10.4	3.0	12.5	3.0	13.1	3.9
LCL 2-19	8.4	0	10.6	0	10.6	0
Tail 20	14.3	1.0	17.4	1.5	16.6	1.5
Coil C						
Head 1	4.4	1.5	8.1	2.5	10.1	1.5
UCL 2-19	7.3	3.4	11.2	3.4	11.2	2.9
LCL 2-19	5.2	0	9.1	0	9.4	0
Tail 20	9.0	2.0	15.9	1.0	18.3	2.0
Coil D						
Head 1	21.3	2.5	13.3	0.5	17.3	1.0
UCL 2-19	10.4	3.6	13.4	2.8	13.9	2.7
LCL 2-19	8.1	0	11.6	0	12.2	0
Tail 20	23.4	0.5	19.1	2.0	20.3	1.5
Coil E						
Head 1	17.5	2.0	12.5	0	13.0	1.0
UCL 2-19	9.5	3.0	12.5	3.2	12.5	3.8
LCL 2-19	7.6	0	10.4	0	10.0	0
Tail 20	13.4	1.5	16.8	1.0	19.1	1.5

[a] Rockwell B minus 40.

The end sheets of the five coils provided a total of 30 hardness averages (2 sheets times 3 locations times 5 coils). Of that total, 25 hardness averages were outside the control limits for average as established by sheets No. 2 through 19.

At the "1-1/2 inches from band edge" location, all of the ten end sheet averages were outside the control limits for average; at the "12 inches from band edge" location, 7 of the 10 end sheet averages were outside the control limits for average; and at the "center" location, 8 of the ten end sheet averages were outside the control limits for average.

Hardness distribution throughout the length of the coils.

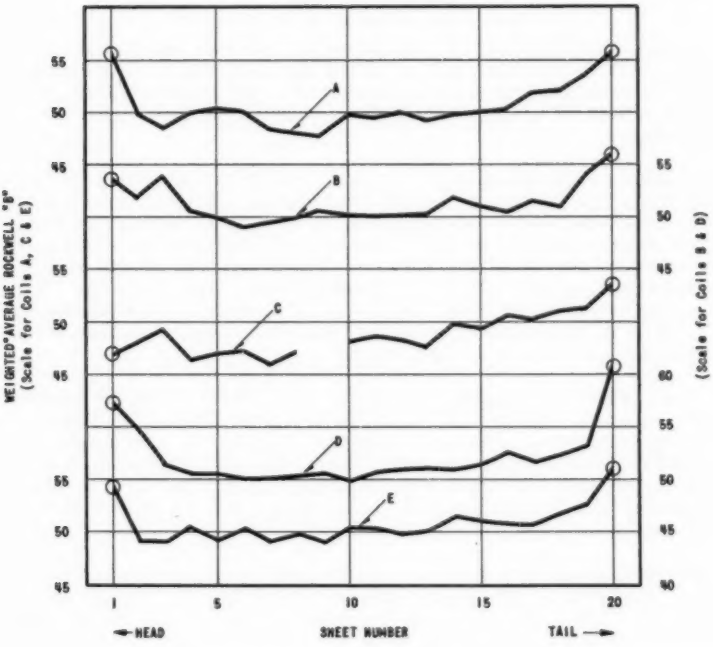
At this point, it is appropriate to inquire about the distribution of hardness values throughout the length of the coils. For this inquiry, the weighted average hardness of each coil is plotted in Figure 4. The weighted average for each sheet was obtained from the following equation.

$$\frac{2\,(E + Q) + C}{5} = \text{weighted average hardness}$$

E is average hardness at 1-1/2 inches from band edge.
Q is average hardness at 12 inches from band edge, which is at approximately one quarter of the width of the sheet.
C is average hardness at center of sheet.

The encircled values are the weighted averages of hardness for the end sheets.

FIGURE 4 - Weighted*Average Rockwell B Hardness
For Each of Five Coils, A to E



NOTE: Points for head and tail sheets are circled.

* See text for explanation of "weighted" average.

In Figure 4, the hardness data for Coil A show an increase of hardness from the central portion of the coil to the tail end. The increase is also evident in Figures 1, 2, and 3 for the three separate locations of hardness measurements. Similarly, the hardness data for Coils B, C, D, and E show an increase from center to tail of the coils.

The increase in hardness from center to tail end of the coils is direct evidence of nonrandom variation of one mechanical property from the center to the tail end of the coils. That variation is characteristic of the manufacture of hot rolled carbon steel sheets in coil form. The hardness increase is associated with the differential cooling of the steel between the center and tail end of the coil as the coil cools from the coiling temperature. This differential cooling is one of the manufacturing variables which must be recognized in any realistic study of this problem.

Similarly, the hardness increases from the center to the head end of the coil, as shown in the curves for Coils A, B, D, and E. That hardness increase also is associated with differential cooling of the coil.

Hardness Distribution Across the Coil. For the particular coils in this case history, another manufacturing variable should be mentioned, namely, the method of deoxidizing the steel. The coils studied were made from a heat of rimmed steel. Consideration of that type of steel is pertinent.

In nearly all steelmaking processes, the principal reaction is the combination of carbon and oxygen to form a gas. If the oxygen available for this reaction is not removed prior to or during casting (by the addition of silicon or some other deoxidizer), the gaseous products continue to evolve during solidification. Proper control of the amount of gas evolved during solidification determines the type of steel. If practically no gas is evolved, the steel is termed "killed" because it lies quietly in the molds. Increasing degrees of gas evolution result in semikilled, capped, or rimmed steels.

Rimmed steels are characterized by marked differences in chemical composition across the section and from top to bottom of the ingot. They have an outer rim that is lower in carbon, phosphorus, and sulphur than the average composition of the whole ingot, and an inner portion or core that is higher than the average in those elements. The typical structure of the rimmed steel ingot results from a marked gas evolution during solidification of the outer rim.

During the solidification of the rim, the concentration of certain elements increases in the liquid portion of the ingot. During solidification of the core, there is some increase in segregation in the upper and central portions of the ingot.

The structural pattern of the rimmed steel ingot persists through the rolling process to the final product. (3)

The difference between the average hardness at the "1-1/2 inches from band edge" location and that at the center of the coil width is associated with the difference in carbon content between the rim and core of the ingot. That difference is evident in Table 3 which lists the average hardness at both 1-1/2 and 12 inches from the band edge and the average hardness at the center for Coils A to E, inclusive.

Table 3

Hardness Distribution Across the Coil

Coil	Location of Hardness Measurements		
	1-1/2 in. from band edge	12 in. from band edge	Center
	Average Rockwell B minus 40[a]		
A	8.49	10.76	11.15
B	9.39	11.52	11.84
C	6.25	10.15	10.32
D	9.26	12.47	13.04
E	8.56	11.49	11.26
Average -	8.39	11.28	11.52

[a] Each value in the foregoing table is the average of a total of 72 Rockwell B readings on Sheet Nos. 2-19, inclusive (4 readings on each sheet at each location).

It will be noted that for Coils A to D, inclusive, the average hardness at 12 inches from the band edge (about midway between the band edge and the center of the sheet) lies between the values for the center and 1-1/2 inches from the band edge.

Evaluation of the Hardness of a Coil. The foregoing data reveal two nonrandom distributions of hardness: (1) along the length of the coil, associated with differential cooling of the coil from the coiling temperature; and (2) across the coil, associated with the carbon variation resulting from the method of deoxidizing the steel.

The foregoing data also show that the results of hardness tests on the end sheets are not readily related to the hardness of the intervening sheets.

If the coil cannot be cut into two or more coils for sampling purposes, how can the hardness of the coil be evaluated? The answer is to rely on appropriate manufacturing controls which aid the production of coils having property values that lie within predictable limits.

While the development of such controls is outside the scope of this paper, reference (4) discusses these as applied to both hot rolled and cold rolled sheets.

Exhibit A

Significant Manufacturing Data on Five Coils of Hot Rolled Carbon Steel Sheets

Grade - Rimmed - 0.10-0.15 per cent carbon

Gage - 0.1090 inch, size - 45 x 202-7/8 inches

Treatment - hot rolled on 80-inch hot strip mill and sheared

Ladle analysis, per cent -

C	Mn	P	S	Si	Cu	Ni	Cr
.12	.44	.008	.032	.006	.08	.03	.03

Coil weight - approximately 17,000 lb.

Number of sheets to a coil - approximately 60

Hardness test locations - every three sheets - at 1-1/2 inches from band edge, 12 inches from band edge, and at center of sheet.

Hot Rolling Temperatures

Coil No.	Ingot and Slab	Temperature, degrees Fahrenheit		
		Roughing	Finishing	Coiling
A	3-1	1960	1600	1260
B	12-1	1960	1600	1270
C	2-1	1940	1600	1270
D	7-1	1940	1590	1255
E	10-1	1960	1580	1250

(1) Sullivan, John W. W.: Applicability and Inapplicability of MIL-STD-105A. Quality Control Conference Papers, 1952, American Society for Quality Control, New York, pp. 275-279.

(2) ASTM Manual on Quality Control of Materials. American Society for Testing Materials, Philadelphia, January 1951, 4th printing, September 1954, p. 63.

(3) Carbon Steel Sheets. American Iron and Steel Institute, New York, June 1954, pp. 6, 7.

(4) Smith, H. C.: Consideration of Heating, Rolling, and Annealing as Factors in the Control of Quality Cold Rolled Sheets. American Iron and Steel Institute Yearbook, 1954, pp. 153-169.

THE MASTER CONTROL SYSTEM

Jean-Claude R. Iafforgue
Canadian General Electric Company Limited

The best definition of Quality Control stands to my mind as "Better Quality at Lower Cost." This means, in particular, reduction of manufacturing losses. This was precisely the objective of our Manufacturing people when they approached our Statistical Methods Section in Schenectady, one of General Electric consulting groups. They wanted a Quality Control System that would be instrumental in reducing manufacturing losses. This system should be so designed to feed back inspection data:

1) To provide the foremen with a tool they could use to prevent defects from happening.
2) To serve as an instrument of accountability for supervision at any level.
3) To pin-point, on a daily basis, problems requiring action.

Furthermore, this system should entail very little additional expenses.

Our Statistical Methods Section surveyed the problem and established four basic points:

1) The value of attribute data is largely underestimated. An awful lot of attribute data is usually available, but not efficiently used. Therefore our Statisticians thought the data should be presented in an integrated system of control charts pin-pointing the responsibility. Furthermore, attribute data are very easily understood by operators and foremen.

2) This system must be operated by the manufacturing people - mainly operators and foremen - on a daily routine basis. It has to be a tool, not in the hands of a Quality Control Specialist, but in the hands of the manufacturing people; their management will direct them daily in its use, so that it operates efficiently.

3) This system must show a statistical interpretation of the data. Yet, as it is to be handled by operators and foremen, all statistical background, formulae and calculations have to be eliminated. It must be simple to become part of the daily routine. It must be pin-pointing so that conclusions are apparent at a glance.

4) The component parts of this system should be integrated to reflect the whole manufacturing operations. Here again this integration must be pin-pointing and conclusions apparent at a glance.

Those four basic considerations were followed by our Statistical Methods Section, who, together with Manufacturing, Engineering, Inspection and Quality Control people developed what we call the "Master Control System". It is described in the October 1955 issue of the "Industrial Quality Control" magazine by Mr. N.P. Demos, from our Statistical Methods Section. He authorized me to use his article to prepare this paper and I took advantage of his permission.

This system can be divided into three basic elements:

1) The Number Defective Table - it eliminates usage of any formula or complicated calculation.
2) The Master Control Sheet - a convenient and efficient way of presenting the data.
3) The Principle of Pyramiding - it shows how we integrate our data.

1) The Number Defective Table

This system is designed to be handled by operators and foremen. Therefore, control limits must be available to them without calculation. The Number Defective Table fills this purpose. Figure I shows an excerpt of it. Entering the table with the percent defective and the number of units inspected, for instance 5.6% and 280 respectively, the statistical control limits are found, 5 and 26 for our example. They are the first points out of control.

This table is based on the binominal distribution and the number defective formula $\bar{p}n \pm 2.58\sqrt{\bar{p}n(1-\bar{p})}$ was used. The limits are expressed in number of defective units rather than in percentage of defective units, as it is easier to use with the Master Control Sheet.

2.58σ was used instead of 3.00σ. It gives 99% certainty instead of 99.7%. Only 0.7% certainty is lost for a gain in sensitivity of 0.84σ.

The table gives limits for 86 values of $\bar{p}$ and 130 values of n. Interpolation may be used for intermediate values if greater accuracy is desired, as the number defective formula may be considered linear in such a small interval.

The table is available in two forms: a large single sheet or a pamphlet.

The values of $\bar{p}$ and n listed in the table go up to 30% and 10,000 respectively. Techniques have been developed to extend the use of the table for values of $\bar{p}$ and n greater than those. In the formula $\bar{p}n \pm 2.58\sqrt{\bar{p}n(1-\bar{p})}$, $\bar{p}$ and n are present as a product $\bar{p}n$. Consequently, one may enter the table with any combination of $\bar{p}$ and n whose product is the same as the actual $\bar{p}$ and n for which limits are being sought. Some error is introduced by not changing the $1-\bar{p}$ term, but this error is of no consequence for most practical uses. Figure II shows examples for $\bar{p}$ = 50% and n's of 100, 1000 and 5000. The error introduced widens the limits.

Our Statistical Methods Section recommends this technique for values of $\bar{p}$ up to 50%. For $\bar{p}$ greater than 50%, it is recommended to use the percent effective $\bar{p}' = 1-\bar{p}$. Then, the lower limit for the Number Effective would be substracted from n to obtain the upper limit for the Number Defective; similarly the upper limit for the Number Effective would be substracted from n to obtain the lower limit for the Number Defective. Figure III shows an example for $\bar{p}$ = 80% and n = 1000.

The Number Defective Table may also be used to obtain limits for the Poisson distribution. When we compare the Poisson formula $\bar{u}n \pm 2.58\sqrt{\bar{u}n}$ with the binominal formula $\bar{p}n \pm 2.58\sqrt{\bar{p}n(1-\bar{p})}$, we find that the only difference between the two is the term $1-\bar{p}$. Then we can use

the same technique as described above to obtain limits where $\bar{p}$'s and n's are off the table. But here we can minimize the error by choosing $\bar{u}$ as small as possible. Figure IV illustrates this point for $\bar{u}$'s of 0.05, 0.5 and 5 and n=100. (It is to be noted that $\bar{u}$ is the average number of defects per unit. Therefore, for $\bar{u} = 0.005$ the table must be entered at $\bar{p} = 0.5\%$).

Thus, by providing operators and foremen with copies of the Number Defective Table and instructing them in its use, we enable them to examine statistically their attribute data without the necessity of learning statistical mathematics or computing the limits.

2) The Master Control Sheet

The next step is to present the data in an orderly and efficient manner. This is accomplished through the use of the Master Control Sheet.

Figure VII shows different types of Master Control Sheet used at the different levels of the manufacturing structure. They are all very similar, although some differences exist which will be pointed out as we describe them. Our plant is manufacturing major appliances: refrigerators, ranges, washing machines, dryers. We make many parts going into those products and finish them all, either by plating, vitreous enameling or baked enameling, and assemble them into finished goods. This gives you an idea of the variety of operations we have to control.

The examples shown on Figure VII are from our Vitreous Enamel Department.

The left-hand column of the sheet shows:

A) At the operator's level, a breakdown of the defects with their process average in the next column. In the case of our vitreous enamel, we only divide defects into two categories: department defects (burn-off, light or heavy spray, enamel lumps, chipping, etc.) and surface defects (blisters, water and oil marks, surface dirt, etc.). However, in the case of finished products, there might be up to 150 different defects, each one with its process average.

B) At the foreman's level, the name of the part.

C) At other levels, the name of the person responsible for the action to be taken.

The next columns on all sheets are identical. The actual number of defects is compared to the "expected" number of defects, as it will be explained later. There is finally one column per day where actual and expected number of defects are recorded.

The bottom row shows the total of both actual and expected number of defects.

The figures out of control on the high side are circled in red (full circle in Figure VII), on the low side in green (dotted circle in Figure VII). Points out of control are therefore apparent at a glance.

Other advantages may be pointed out:

1) The breakdown of the process averages shows the foreman where he must concentrate his action.

2) This breakdown also increases the sensitivity; on the range panel chart for instance, there are 9 points out of control in the breakdown against 4 in the total.

3) All the information is on one sheet of paper, which makes it easier for the human mind to grasp than if scattered on different sheets.

4) Limits are automatically checked against the exact n, which is an advantage over a $\bar{p}$ chart where n varies. This will be shown later, as it is related to the notion of expected number of defects.

Each month all rows are added horizontally and the process averages recalculated. It might be well, at this point, to discuss the question of what process averages should be used.

Whenever a process average decreases at the end of a month, our management is quite satisfied. But if it increases, management claims that, since we have been able to perform at a lower level, we should be able to maintain it. It is possibly true, but the fact remains that, for an unknown reason, a process average sometimes goes up. And in this case, we must take the new high process average if we want to retain our statistical interpretation of the data.

The example shown on Figure V illustrates this. Although the same reasoning applies with a variable number inspected n, we made it constant for the sake of simplicity. (n = 1000).

A certain process was stabilized around $\bar{p} = 1\%$. For an unknown reason, this process changes to $\bar{p} = 4\%$.

Let us assume we retain $\bar{p} = 1\%$ and use it to compute our limits on our master control sheet. The process will be shown out-of-control in the red, which is all right.

However, we are constantly working on this process, trying to improve it. Its average might eventually go down and even stabilize itself around a different level, let us say 2%, but since we still use $\bar{p} = 1\%$ to compute our limits, a process running at $\bar{p} = 2\%$ may show out-of-control, as on Figure V. Therefore, our master control sheet will show our process out-of-control in the red, in the same fashion as when the process was running at $\bar{p} = 4\%$. We will have missed the definite change - due to an assignable cause - which occurred when the process average decreased from 4% to 2%.

Had we changed our process average to 4%, we would have shown out-of-control points in the green on our master control sheet where the change from 4% to 2% took place. We would have therefore been able to find the reason for this change and incorporate it as a part of our operation.

The compromise with the management is therefore as follows:

Take the lowest process average (1% in this example) as a boggey, but use the actual process average in your control system. It is by working on your out-of-control points that you will succeed to bring the process average down.

We issue the process averages monthly, and point out the ones that are too high. Everybody knows then that it is not sufficient to keep the process in control. Green circles must be obtained so that process averages may be brought back where they should be.

3) The Principle of Pyramiding

The third element - and the most valuable - is the integration of the data. This is what we call pyramiding and how we give management the tool they really need.

The problem we have to solve is how to combine defects. An example will help us to expose its solution. Let us consider 100 electric ranges having an average number of defects per unit $\bar{u}_1 = 0.9$ and 150 refrigerator doors for which $\bar{u}_2$ is0.02 (if a door is rejected for only one defect, you will note that the percent defective $\bar{p}$ is the same as the number of defects per door; $\bar{p}$ would then be 20%.

We will make here an assumption which is very close to the truth in almost all practical cases. We will assume that we are dealing with Poisson distributions. We know that if we have several Poisson distributions $\bar{c}_1$, $\bar{c}_2$, etc., their standard deviations being respectively $\sqrt{\bar{c}_1}$, $\sqrt{\bar{c}_2}$, etc., the combined distribution $\bar{c}=\bar{c}_1+\bar{c}_2+\ldots$ has a standard deviation $\sqrt{\bar{c}}=\sqrt{\bar{c}_1+\bar{c}_2}+\ldots$

Applying this property to our example, we have $\bar{c}_1 = \bar{u}_1 n_1 = 0.9 \times 100 = 90$ and $\bar{c}_2 = \bar{u}_2 n_2 = 0.02 \times 150 = 30$. We may say, we normally expect 90 defects out of our 100 ranges and 20 defects out of our 150 refrigerator doors. We may also say we expect $\bar{c} = \bar{c}_1 + \bar{c}_2 = 90 + 30 = 120$ defects out of the 100 ranges and 150 refrigerator doors. $\bar{c}$, $\bar{c}_1$ and $\bar{c}_2$ are what we call the "expected number of defects". They are the averages of three Poisson distributions whose standard deviations are respectively $\sqrt{\bar{c}}$, $\sqrt{\bar{c}_1}$ and $\sqrt{\bar{c}_2}$.

We have shown that we can combine the defects by a mere addition. Using our Number Defective Table with the technique developed for the Poisson, we can find our limits. The problem is therefore completely solved, technically and practically.

The most efficient way to apply what we just learned is to follow the organization structure of the manufacturing department, hence the word "pyramiding".

Figure VI shows an example of an organization chart and Figure VII the Master Control Sheets following it, from Foreman 9 right up to the Plant Manager (16).

Foreman 9 is in charge of our Vitreous Enamel operations. Six major parts are processed through this department: refrigerator liner, refrigerator inner door, washing machine tub, range body, range top, range panel. We start with a chart for each one of those parts (only 2 are shown on Figure VII due to space - range top and range panel). The totals of actual and expected number of defects from those 6 charts are transferred to Foreman 9's chart.

Both totals - actual and expected - from Foreman 9's chart are transferred to General Foreman 13's chart where the totals from Foreman 8's chart also appear.

Totals from General Foreman 13's chart together with totals from the charts of General Foreman 10, Foreman 11, General Foreman 12 and Foreman 14 will form the chart of Superintendent 15. His totals will be the only ones to appear on the chart of the Plant Manager (16).

On each chart the points out-of-control are circled either in red (full) or green (dotted).

The graph on the Plant Manager's chart is optional. It shows the difference between the actual and expected number of defects, on the positive side if actual is greater than expected, on the negative side if the opposite. Red and green circles on the graph correspond to the out-of-control points as shown in the Superintendent's totals.

We will conclude this paper with a few observations about this system.

The lower the level of the chart in the pyramid, the more sensitive the control becomes. Hence, the persons who need to take action have the pin-pointing information to guide them daily.

The higher the level in the pyramid, the more detail is eliminated, but the out-of-control conditions revealed are more important.

Figure VII shows we had a lot of trouble on August 15 in the Vitreous Enameling Department due to surface defects. This out-of-control condition at the foreman's level was serious enough to reflect as an out-of-control point on the Plant Manager's chart. Troubles of minor importance will not show above the operator's level (surface defects on range top and panel on August 24) or the foreman's level (surface defects on range top on August 19). Problems of medium importance may show up to the general foreman's level (surface defects on range panel on August 16).

In other words, the management level up to which an out-of-control condition shows, will be automatically related to the importance of the problem.

The charts are so directly connected to each other that the entire mass of data directly below a person in the pyramid becomes easily and immediately available at his discretion.

We have seen how to go up the pyramid. We may similarly go from one Master Control Sheet to the next, from the Plant Manager right down to the operator.

The importance of each superior discussing each circle on his chart daily with the subordinates concerned cannot be overemphasized. Any person in the pyramid can activate that portion directly below him by following this rule. A plant manager thus devoting a few minutes of his time per day can be assured that all the persons in his organization are regularly investigating and taking action on the out-of-control conditions that are indicated on their respective charts.

You noticed that the total shown in red on a foreman's sheet is what will be shown on his superior's sheet, the general foreman. If this general foreman follows the above-mentioned rule, the foreman must know why he is in the red. If he does not know once, he will certainly make sure he knows the second time it happens; a superior never likes "I do not know" as an answer too many times.

A good deal of the effectiveness of this system stands right there. Nobody likes to be asked questions when in trouble. And the best way of avoiding them is to remain in control ... or in the green - everybody likes to be congratulated. There is a very definite psychological effect in the use of the red and green circles.

This system is extremely flexible. The check points may be changed, the organization structure modified, all that is needed is the addition or substraction of a few Master Control Sheets. This may be done at any time. However, what already exists is still valid.

This system can be used either in the case of 100% or sampling inspection, as we always considered n as the number inspected. Its use is very wide since in any manufacturing operations, there are units and defects. It may be set up in three steps:

1) Selection of the check points.
2) Grouping of the defects on the Master Control Sheets at the operator's level so that they form a definite entity.
3) Integration of the data following the organization chart.

It takes a girl about one hour a day to go around the plant and pick-up the figures from the foremen's sheets, transfer them on the general foremen's, superintendent's and plant manager's sheets. The sheet of paper she uses while doing this is given to the Quality Control Manager at the completion of the tour, so that he also has the entire picture of the manufacturing operations as far as quality is concerned.

We do not make any copy of the Master Control Sheets. Each one is kept by the responsible individual. We pick them up at the end of each month, when we replace them by the new ones, showing the new process averages.

We had Statistical Quality Control since 1950 and realized some spectacular quality improvements, but all of a localized effect. Through the use of the Master Control System, we improved our quality picture all across the plant, reducing our number of defects by approximately 40% in one-and-a-half year.

Bibliography

"The Master Control System in General Electric" by N.P. Demos, Statistical Methods Section, General Electric Company, Schenectady, N.Y., October 1955 issue of "Industrial Quality Control".

P% / N	5.0	5.2	5.4	5.6	5.8	6.0	6.5	P% / N
250	3 22	3 23	4 23	4 24	4 25	5 25	6 27	250
260	3 23	4 23	4 24	4 25	5 25	5 26	6 28	260
270	4 23	4 24	4 25	5 25	5 26	6 27	7 29	270
280	4 24	4 25	5 25	5 26	6 27	6 28	7 29	280
290	4 25	5 25	5 26	6 27	6 28	6 28	8 30	290
300	5 25	5 26	6 27	6 28	6 28	7 29	8 31	300
310	5 26	6 27	6 28	6 28	7 29	7 30	8 32	310
P% / N	5.0	5.2	5.4	5.6	5.8	6.0	6.5	P% / N

FIG. 1

Limits Wanted for	Correct Limits Using the ND Formula	Using These Altered Values of $\bar{p}$ and n	These limits are obtained from ND Table
$n = 100$ $\bar{p} = 50\%$	37 63	$n = 200$ $\bar{p} = 25\%$	34 66
$n = 1{,}000$ $\bar{p} = 50\%$	459 541	$n = 2{,}000$ $\bar{p} = 25\%$	450 550
$n = 5{,}000$ $\bar{p} = 50\%$	2408 2592	$n = 10{,}000$ $\bar{p} = 25\%$	2388 2612

FIG. 2

	ND Formula		Number Defective Table	
	Correct Limits for No. Defective		Limits for No. Effective	Limits for No. Defective
$\bar{p} = 80\%$ $n = 1{,}000$	767 833	$\bar{p}' = 20\%$ $n = 1{,}000$	167 233	767 833

FIG. 3

Limits Wanted for	Correct Limits Using $\bar{u}$ Formula	Using These Altered Values for $\bar{u}$ & n	These limits are obtained from the ND Table
$\bar{u} = 0.05$ $n = 100$	— 11	$\bar{u} = 0.005\ (0.5\%)$ $n = 1000$	— 11
$\bar{u} = 0.5$ $n = 100$	31 69	$\bar{u} = 0.005\ (0.5\%)$ $n = 10{,}000$	31 69
$\bar{u} = 5.0$ $n = 100$	442 558	$\bar{u} = 0.05\ (5.0\%)$ $n = 10{,}000$	443 557

FIG. 4

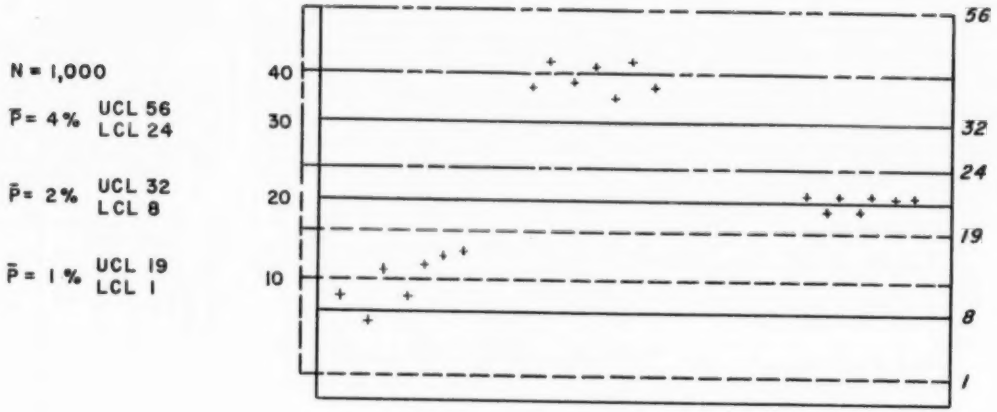

N = 1,000
$\bar{P}$ = 4% UCL 56 LCL 24
$\bar{P}$ = 2% UCL 32 LCL 8
$\bar{P}$ = 1% UCL 19 LCL 1
40
30
20
10
56
32
24
19
8
1

FIG. 5

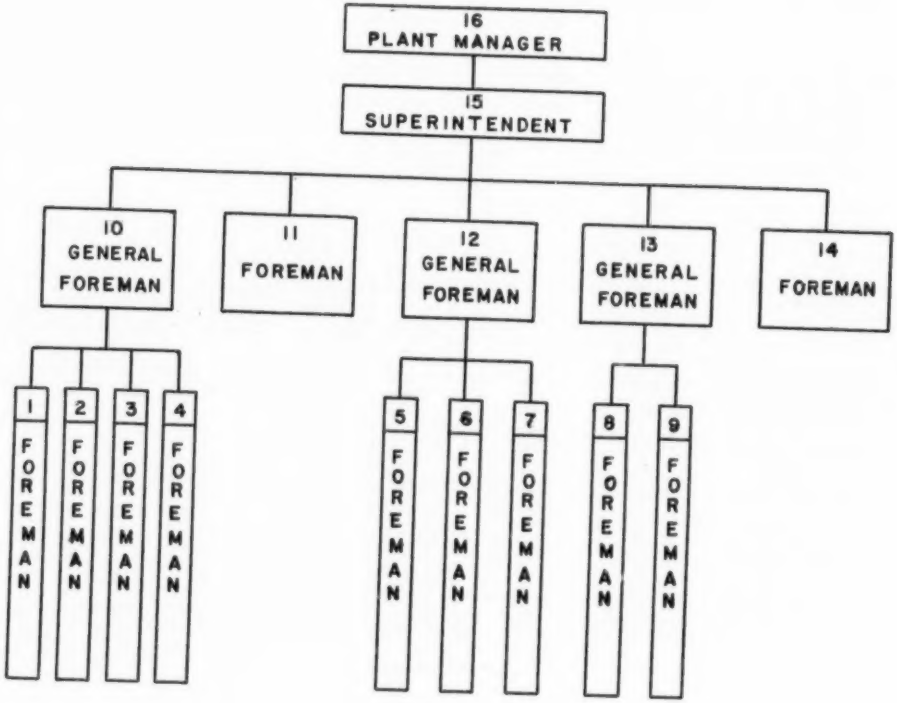

16
PLANT MANAGER
15
SUPERINTENDENT
10
GENERAL
FOREMAN
11
FOREMAN
12
GENERAL
FOREMAN
13
GENERAL
FOREMAN
14
FOREMAN
1
FOREMAN
2
FOREMAN
3
FOREMAN
4
FOREMAN
5
FOREMAN
6
FOREMAN
7
FOREMAN
8
FOREMAN
9
FOREMAN

FIG. 6

cont'd on fig.7 sht.2

AUGUST		RANGE TOP									
DEFECT	P/A	DATE	15	16	17	18	19	22	23	24	25
DEPART.	1.6	ACT.	0	—	6	0	0	—	0	0	(6)
		EXP.	2	—	3	1	1	—	1	2	1
SURFACE	15.4	ACT.	(30)	—	(62)	(23)	(29)	—	16	(29)	18
		EXP.	18	—	29	10	12	—	9	17	10
TOTAL	/	ACT.	30	—	(68)	(23)	(29)	—	16	29	(24)
		EXP.	20	—	32	11	13	—	10	19	11

AUGUST		RANGE PANELS									
DEFECT	P/A	DATE	15	16	17	18	19	22	23	24	25
DEPART.	2.2	ACT.	6	0	(0)	(0)	0	(0)	0	0	2
		EXP.	12	5	7	9	6	8	6	6	6
SURFACE	13.2	ACT.	(132)	(41)	(75)	(93)	35	(74)	54	(61)	57
		EXP.	75	27	43	54	37	49	39	38	37
TOTAL	/	ACT.	(138)	41	(75)	(93)	35	(74)	54	61	59
		EXP.	87	32	50	63	43	57	45	44	43

FIG. 7 SHT. 1

cont'd on fig.7 sht. 3

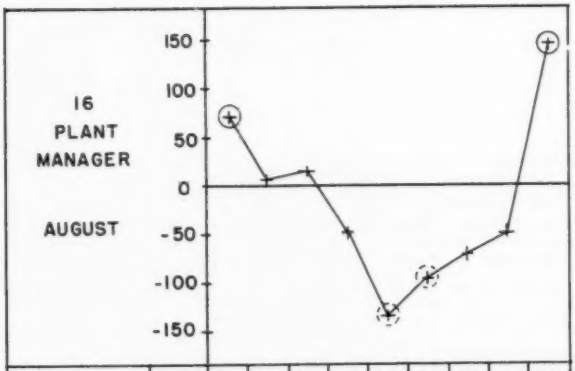
GENERAL FOREMAN-13

AUGUST FINISHING OPERATIONS	DATE	15	16	17	18	19	22	23	24	25
ACTION BY										
FOREMAN-8	ACT.	70	45	55	67	24	31	45	62	58
WHITE PAINT	EXP.	55	58	66	62	32	42	62	76	53
FOREMAN-9	ACT.	(313)	(134)	(191)	(243)	191	94	80	107	108
VITR. ENAMEL	EXP.	213	96	108	171	194	94	83	85	89
TOTAL	ACT.	(383)	179	(246)	(310)	215	125	125	169	166
	EXP.	268	154	174	233	226	136	145	161	142

FOREMAN-9

AUGUST VITREOUS ENAMEL	DATE	15	16	17	18	19	22	23	24	25
PART										
REFRIGERATOR LINER	ACT.	12	6	12	7	7	2	3	4	7
	EXP.	10	10	10	10	7	8	10	8	12
REFRIGERATOR INNER DOOR	ACT.	—	—	—	—	19	(7)	(7)	—	8
	EXP.	—	—	—	—	17	20	18	—	12
WASHING MACHINE TUB	ACT.	(114)	45	—	78	88	—	—	—	—
	EXP.	86	38	—	70	104	—	—	—	—
RANGE BODY	ACT.	(19)	(42)	(36)	(42)	13	11	—	13	10
	EXP.	10	16	16	17	10	9	—	14	11
RANGE TOP	ACT.	30	—	(68)	(23)	(29)	—	16	29	(24)
	EXP.	20	—	32	11	13	—	10	19	11
RANGE PANELS	ACT.	(138)	41	(75)	(93)	35	(74)	54	61	59
	EXP.	87	32	50	63	43	57	45	44	43
TOTAL	ACT.	(313)	(134)	(191)	(243)	191	94	80	107	108
	EXP.	213	96	108	171	194	94	83	85	89

FIG.7 SHT. 2



15 SUPERINTENDENT	DATE	15	16	17	18	19	22	23	24	25
	ACT.	887	712	680	723	646	445	520	691	851
	EXP.	815	709	670	769	783	541	590	740	716

AUGUST	SUPERINTENDENT- 15									
ACTION BY	DATE	15	16	17	18	19	22	23	24	25
GENERAL FOREMAN-10	ACT.	347	380	273	225	246	206	239	338	469
	EXP.	393	392	322	364	357	292	273	372	334
FOREMAN-11	ACT.	3	20	38	20	24	28	27	39	37
	EXP.	3	19	49	26	21	20	26	34	27
GENERAL FOREMAN-12	ACT.	153	133	121	165	158	78	126	143	174
	EXP.	148	140	122	143	176	90	143	170	210
GENERAL FOREMAN-13	ACT.	383	179	246	310	215	125	125	169	166
	EXP.	268	154	174	233	226	136	145	161	142
FOREMAN-14	ACT.	1	0	2	3	3	8	3	2	5
	EXP.	3	4	3	3	3	3	3	3	3
TOTAL	ACT.	887	712	680	723	646	445	520	691	851
	EXP.	815	709	670	769	783	541	590	740	716

FIG. 7 SHT. 3

LE SYSTEME DU MAITRE-CONTROLE

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(Les figures auxquelles le texte réfère se trouvent à la fin de la traduction anglaise qui précède.)

Le Contrôle de la Qualité, à mon sens, se définit: Meilleure qualité à un coût moindre. Cela signifie, en particulier, réduction des pertes de fabrication. Notre personnel de fabrication visait précisément cet objectif quand il aborda notre section des Méthodes Statistiques à Schenectady, un des groupes de consultants de General Electric. Il voulait un Système de Contrôle de la Qualité qui contribuerait à réduire les pertes de fabrication. Ce système devait être conçu de façon à s'alimenter des données d'inspection afin de:

1) Fournir aux contre-maîtres un outil pour empêcher les défauts de se produire.
2) S'en servir comme un baromètre de performance à n'importe quel niveau de direction.
3) D'indiquer journalièrement les problèmes qui demandent correction.

De plus, ce système n'occasionnera que très peu de frais additionnels.

Notre section des Méthodes Statistiques étudia la question et établit les quatre points fondamentaux suivants:

1) Nous sous-estimons grandement la valeur des attributs disponibles, et ceux-ci ne sont pas utilisés efficacement. Nos statisticiens songèrent donc à les présenter en un système de tableaux qui les intègre et met en relief la responsabilité.

2) Il appartient au personnel de fabrication, principalement opérateurs et contre-maîtres, de faire marcher ce système journalièrement. De plus, les contre-maîtres et les opérateurs comprennent très facilement les données par attributs. Il est essentiel que ce système soit un instrument, non pas dans les mains du spécialiste en Contrôle de la Qualité, mais dans celles du personnel de fabrication. Tous les jours la direction de la fabrication donnera des instructions à son personnel afin que ce système fonctionne efficacement.

3) Ce système retiendra une interprétation statistique des données. Toutefois, puisque les opérateurs et les contre-maîtres le manipuleront, l'élimination de toute théorie statistique, des formules et des calculs s'avèrera nécessaire. Il importe que ce système soit présenté sous une forme simple afin de s'adapter à leur routine quotidienne. Il importe aussi qu'il mette en relief les conclusions afin que celles-ci soient apparentes à première vue.

4) Les parties composant ce système seront intégrées de manière à refléter l'ensemble des opérations de fabrication. Cette intégration sera frappante et les conclusions apparaîtront au premier coup d'oeil.

Notre section des Méthodes Statistiques, en possession de ces

quatre principes de base, développa, en collaboration avec le personnel technique de la Fabrication, de l'Inspection et du Contrôle de la Qualité, ce que nous appelons le "Système du Maître-Contrôle." Incidemment, il est décrit dans l'Industrial Quality Control Magazine, numéro d'octobre 1955, par M. N.P. Demos de notre section des Méthodes Statistiques. M. Demos m'autorisa à puiser dans son article pour préparer ce papier. Je profitai de sa permission.

Ce système se divise en trois éléments de base:

1) La Table du Nombre Défectible - elle élimine l'emploi de toute formule ou calculs compliqués.
2) La Feuille du Maître-Contrôle - une manière facile et efficace de présenter les données.
3) Le Principe de Pyramider - il montre comment nous intégrons nos données.

1) La Table du Nombre Défectible

Ce système est conçu de façon à être manipulé par les opérateurs et les contre-maîtres. Nous nous bornerons donc à leur fournir des limites de contrôle en éliminant toute mathématique statistique. La Table du Nombre Défectible atteint ce but. La Figure I en est un extrait. Supposons que nous entrions dans la table avec le pourcentage de défauts et le nombre d'unités inspectées, par exemple: 5.6% d'une part et 280 d'autre part. Dans ce cas, les limites statistiques de contrôle trouvées sont 5 et 26. Ce sont les premiers chiffres hors de contrôle.

Cette table est basée sur la distribution du binôme et nous utilisons la formule du nombre défectible: $\bar{p}n \pm 2.58\sqrt{\bar{p}n(1-\bar{p})}$. Les limites s'expriment en nombre d'unités défectibles plutôt qu'en pourcentage d'unités défectibles pour faciliter l'emploi de la feuille du Maître-Contrôle.

2.58σ fut préféré à 3.00σ. Nous obtenons 99% de certitude au lieu de 99.7%. Nous gagnons 0.84σ en sensibilité et ne perdons que 0.7% de certitude. La table fournit des limites pour 86 valeurs de $\bar{p}$ et 130 valeurs de n. Pour plus de précision, s'il s'agit de valeurs intermédiaires, nous pouvons interpoler, la formule du nombre défectible étant approximativement linéaire en pareil cas.

La table se présente sous deux formes: une seule grande feuille ou une brochure.

Les valeurs de $\bar{p}$ et n listées dans la table vont jusqu'à 30% et 10,000 respectivement. Des techniques furent développées afin d'étendre l'emploi de la table pour des valeurs de $\bar{p}$ et n plus grandes. Dans la formule $\bar{p}n \pm 2.58\sqrt{\bar{p}n(1-\bar{p})}$, $\bar{p}$ et n s'y trouvent comme un produit $\bar{p}n$. En conséquence, nous pouvons entrer dans la table avec n'importe quelle combinaison de $\bar{p}$ et n dont le produit est le même que celui de $\bar{p}$ et n pour lesquels nous cherchons les limites. Une certaine erreur se glisse en ne changeant pas le terme $1-\bar{p}$, mais elle est négligeable dans la plupart des cas. La Figure II nous fait voir des exemples pour $\bar{p}$=50% et n=100, 1000 et 5000. L'erreur introduite élargit les limites.

Notre section des Méthodes Statistiques recommande cette technique pour des valeurs de $\bar{p}$ allant jusqu'à 50%. Pour des valeurs de $\bar{p}$ supé-

rieures à 50%, cette section recommande d'utiliser le pourcentage efficace $\bar{p}'=1-\bar{p}$. Dans ce cas, la limite inférieure pour le nombre efficace est soustraite de n afin d'obtenir la limite supérieure pour le nombre défectible. D'une façon semblable, la limite supérieure pour le nombre efficace est soustraite de n afin d'obtenir la limite inférieure pour le nombre défectible. La Figure III nous donne un exemple pour $\bar{p}=80\%$ et $n=1000$.

La Table du Nombre Défectible peut également servir à l'obtention de limites pour la distribution de Poisson. Quand nous comparons la formule de Poisson $\bar{u}n\pm2.58\sqrt{\bar{u}n}$ avec la formule du binôme $\bar{p}n\pm2.58\sqrt{\bar{p}n(1-\bar{p})}$, nous remarquons que la seule différence entre les deux réside dans le terme $1-\bar{p}$. Donc la même technique que celle décrite pour obtenir les limites quand $\bar{p}$ et n sont en dehors de la table s'emploie. Mais nous pouvons ici réduire l'erreur en choisissant $\bar{u}$ aussi petit que possible. La Figure IV illustre ce point pour des valeurs de $\bar{u}=0.05$, 0.5 et 5 et $n=100$. Notons que $\bar{u}$ représente le nombre moyen de défauts par unités. Donc, pour $\bar{u}=0.005$, il faut entrer dans la table à $\bar{p}=0.5\%$.

Ainsi, en pourvoyant les opérateurs et les contre-maîtres avec des copies de la table du nombre défectible et en leur expliquant la manière de l'employer, nous leur fournissons les moyens d'examiner, d'une façon statistique, leurs données par attributs, sans qu'il leur soit nécessaire d'apprendre les mathématiques statistiques ou de calculer les limites.

2) La Feuille du Maître-Contrôle

Il nous faut maintenant présenter les données d'une manière efficace et méthodique. La feuille du Maître-Contrôle se prête facilement à l'accomplissement de ce travail.

La Figure VII en exhibe plusieurs modèles utilisés aux différents échelons du personnel de la fabrication. Elles se ressemblent toutes quoiqu'elles diffèrent par certains points que nous soulignerons au fur et à mesure que nous les rencontrerons.

Notre usine fabrique les appareils majeurs: refrigérateurs, poêles électriques, lessiveuses, sécheuses. Nous manufacturons un grand nombre de pièces entrant dans ces produits et nous les finissons toutes, soit par électro-placage, par émaillage vitreux ou émaillage cuit et nous les assemblons en des produits finis. Ceci vous donnera une idée de la variété des opérations que nous devons contrôler.

Les exemples de la Figure VII sont tirés de la section de l'émail vitreux.

La colonne à gauche de la feuille fait ressortir:

A) Au niveau de l'opérateur, une liste des défauts avec leur moyenne du procédé dans la colonne suivante. Dans le cas de l'émail vitreux, nous divisons les défauts en deux catégories: défauts de section (brûlure, couche d'émail légère ou épaisse, grumeau, écaillage, etc.), et défauts de surface (égratignures, taches d'eau et d'huile, souillure superficielle, etc.). Pour un produit fini, nous pouvons réunir jusqu'à 150 défauts, chacun avec sa moyenne du procédé.

B) Au niveau du contre-maître, le nom de la pièce.

C) Aux autres niveaux, le nom de la personne responsable de l'application des mesures qui s'imposeront.

La colonne suivante est identique sur toutes les feuilles. Nous établissons une comparaison entre le nombre réel de défauts et le nombre prévu de défauts. Nous nous étendrons sur ce point plus loin. Il y a, enfin, une colonne par jour où l'on enregistre le nombre réel et le nombre prévu de défauts. La ligne du bas indique le total des deux: le nombre réel et le nombre prévu de défauts.

Les nombres hors de contrôle, ceux qui sont plus grands que les limites supérieures, sont encerclés en rouge (cercle plein dans la Figure VII), des cercles verts entourent ceux qui sont plus petits que les limites inférieures (cercles pointillés dans la Figure VII). Les points hors de contrôle frappent donc au premier coup d'oeil.

Il existe d'autres avantages que nous pouvons énumérer:

1) Le détail des moyennes du procédé indique au contre-maître où concentrer son attention.

2) Le détail accroît la sensibilité: dans le cas des panneaux des poêles électriques, par exemple, nous apercevons 9 points hors de contrôle dans le détail et 4 dans le total.

3) Tous les renseignements se trouvent sur une feuille de papier. L'esprit les saisit plus facilement que s'ils étaient dispersés sur plusieurs feuilles.

4) Nous vérifions automatiquement les limites avec le n exact, ce qui est un avantage sur le graphique $\bar{p}$, quand n varie. Ceci étant relié à la notion du nombre prévu de défauts, nous y reviendrons plus loin.

Chaque mois, nous additionnons toutes les rangées horizontalement et nous recalculons les moyennes du procédé. Il serait à propos, maintenant, de s'étendre sur la question suivante: quelles moyennes du procédé devons-nous utiliser?

Quand une moyenne du procédé diminue à la fin du mois, notre direction s'en réjouit. Toutefois, si la moyenne du procédé augmente, la direction prétend que, puisque nous avons pu opérer à un niveau plus bas, nous devrions maintenir cette moyenne. Ceci est possible, mais un fait demeure: une moyenne du procédé parfois augmente. Dans un tel cas, nous devons utiliser la nouvelle moyenne du procédé, celle qui est élevée, si nous voulons conserver notre interprétation statistique des données.

La Figure V illustre ce point. Quoique le même raisonnement s'applique quand il s'agit d'un nombre variable inspecté n, nous choisîmes un nombre constant afin de simplifier (n=1000).

Un certain procédé se stabilisa aux environs de $\bar{p}$=1%. Pour une raison inconnue, ce procédé changea à $\bar{p}$=4%.

Supposons que nous conservions $\bar{p}$=1% et que nous l'utilisions pour computer nos limites sur la feuille du maître-contrôle. Le procédé apparaîtra hors de contrôle en rouge, ce qui est normal.

Toutefois, nous continuons de travailler en vue de l'améliorer.

Sa moyenne peut éventuellement baisser, même se stabiliser à un niveau différent, disons 2%, mais puisque nous retenons $\bar{p}$=1% pour computer nos limites, un procédé s'élevant à $\bar{p}$=2% paraîtra hors de contrôle comme le fait voir la Figure V. Aussi, notre feuille du maître-contrôle indiquera notre procédé hors de contrôle en rouge de la même manière que lorsque le procédé était stable à $\bar{p}$=4%. Le changement très net dû à une cause déterminable qui se produisit lorsque la moyenne du procédé diminua de 4% à 2% nous aura échappé.

Aurions-nous modifié notre moyenne du procédé à 4%, nous aurions indiqué des points hors de contrôle en vert sur notre feuille du Maître-Contrôle, quand le changement de 4% à 2% s'effectua. Donc, nous aurions pu découvrir le motif de ce changement et l'incorporer comme un élément de cette opération.

Le compromis avec la direction est alors le suivant:

Prenez la moyenne du procédé la plus basse (1% dans cet exemple) comme but à atteindre, mais utilisez la moyenne du procédé réelle dans votre système de contrôle. C'est en travaillant sur les points hors de contrôle que vous réussirez à abaisser la moyenne du procédé.

Nous publions mensuellement les moyennes du procédé et nous indiquons celles qui sont trop élevées. Ainsi, chacun sait qu'il n'est pas suffisant de garder le procédé en contrôle. L'obtention de cercles verts s'impose afin que les moyennes du procédé soient ramenées à leur niveau normal.

3) Le Principe de Pyramider

Le troisième élément-et le plus précieux-est l'intégration des données: ceci s'appelle pyramider et, ici, nous donnons à la direction l'outil qui lui permettra réellement d'exercer son contrôle.

Nous devons résoudre le problème suivant: comment combiner les défauts. Un exemple facilitera l'exposé de la solution. Considérons 100 poêles électriques ayant un nombre moyen de défauts par unité $\bar{u}$=0.9 et 150 portes de refrigérateurs pour lesquelles $\bar{u}$ est 0.02 (si nous rejetons une porte pour un seul défaut, vous noterez que le pourcentage défectif $\bar{p}$ est le même que le nombre de défauts par porte; $\bar{p}$ serait alors 20%).

Nous faisons, ici, une supposition qui se rapproche grandement de la vérité, dans presque tous les cas pratiques, soit que nous ayons affaire uniquement à des distributions de Poisson. Nous savons que si nous avons plusieurs distributions de Poisson $\bar{c}_1$, $\bar{c}_2$, etc., leur écart standard étant respectivement $\sqrt{\bar{c}_1}$, $\sqrt{\bar{c}_2}$, etc., la distribution combinée est une autre distribution de Poisson dont la moyenne est $\bar{c}=\bar{c}_1+\bar{c}_2$ et l'écart standard $\sqrt{\bar{c}}=\sqrt{\bar{c}_1+\bar{c}_2+\ldots}$.

En appliquant ce principe à notre exemple, nous obtenons $\bar{c}_1=\bar{u}_1n_1=0.9\times100=90$ et $\bar{c}_2=\bar{u}_2n_2=0.02\times150=30$.

Nous pouvons dire que nous prévoyons trouve $\bar{c}=\bar{c}_1+\bar{c}_2=90+30=120$ défauts dans les 100 poêles électriques et les 150 portes de refrigérateurs. Nous appelons $\bar{c}$, $\bar{c}_1$ et $\bar{c}_2$ le nombre prévu de défauts. Ce sont là les moyennes de trois distributions de Poisson dont les écarts standards sont respectivement $\sqrt{\bar{c}}$, $\sqrt{\bar{c}_1}$ et $\sqrt{\bar{c}_2}$.

Nous avons déjà vu la possibilité de combiner les défauts par une simple addition: il n'y a donc qu'à utiliser la Table du Nombre Défectible avec la technique développée pour la distribution de Poisson, pour trouver nos limites. Le problème est complètement résolu théoriquement et pratiquement.

Afin d'appliquer efficacement ce que nous venons d'apprendre il suffit de suivre le plan d'organisation de la section de fabrication, d'où le mot "pyramider".

La Figure VI montre un exemple d'un plan d'organisation et la Figure VII, les feuilles du Maître-Contrôle, le détaillant depuis le contre-maître (9) jusqu'au gérant de l'usine (16).

Le contre-maître 9 est chargé des opérations de l'émail vitreux. Six pièces majeures sont finies par cette section: intérieur de refrigérateur, porte intérieure de refrigérateur, cuve de lessiveuse, bâti de poêle électrique, dessus de poêle électrique, panneaux de poêle électrique. Nous débutons avec un tableau pour chaque pièce (deux seulement sont illustrésesur la Figure VII en raison de l'espace disponible - dessus de poêles électriques et panneaux de poêles électriques. Le total du nombre réel et du nombre prévu de défauts des 6 tableaux est transféré au tableau du contre-maître 9.

Les deux totaux: nombre réel et nombre prévu sont transférés du tableau du contre-maître 9 au tableau du contre-maître général 13. Nous y trouvons également les totaux du tableau du contre-maître 8.

Le tableau du chef de service de fabrication 15, comprendra les totaux du tableau du contre-maître général 13, ainsi que ceux des tableaux du contre-maître général 10, du contre-maître 11, du contre-maître général 12 et du contre-maître 14. Ses totaux apparaîtront seuls sur le tableau du gérant de l'usine (16).

Sur chaque tableau, un cercle rouge ou vert, selon le cas, entourera les points hors de contrôle. Le graphique sur le tableau du gérant de l'usine est facultatif. Il montre la différence entre le nombre réel et le nombre prévu de défauts, positive, si le réel est plus grand que le prévu, négative, dans le cas contraire. Les cercles rouges et les cercles verts sur le graphique correspondent aux points hors de contrôle tels qu'indiqués dans les totaux du chef de service de fabrication.

Nous terminerons ce papier avec quelques commentaires sur ce système.

Plus le niveau du tableau, dans la pyramide est bas, plus la sensibilité du contrôle est grande. En conséquence, les personnes devant agir trouveront l'information qui les guidera journalièrement, d'une façon très apparente.

Plus le niveau dans la pyramide est haut, plus le détail est éliminé mais aussi, plus les conditions hors de contrôle indiquées sont importantes.

Il ressort de la Figure VII tous les ennuis que nous eûmes le 15 août, dans la section de l'Email Vitreux, en raison de défauts de surface. Cet état hors de contrôle, au niveau du contre-maître, fut suffisamment sérieux pour se refléter comme un point hors de contrôle sur le tableau du gérant de l'usine. Les ennuis de moindre importance ne dépassent pas

le niveau de l'opérateur (défauts superficiels sur le dessus et les panneaux de poêles électriques, le 24 août), ou le niveau du contre-maître (défauts superficiels sur le dessus de poêles électriques, le 19 août). Des problèmes d'importance moyenne peuvent se refléter jusqu'au niveau de contre-maître général (défauts superficiels sur les panneaux de poêles électriques, le 16 août).

En d'autres termes, le niveau de direction jusqu'auquel une condition hors de contrôle se reflète se trouvera automatiquement en rapport avec l'importance du problème.

Les tableaux sont si étroitement reliés les uns aux autres que la masse entière des détails directement au dessous d'un individu dans la pyramide devient facilement et immédiatement utilisable à sa discrétion.

Nous vîmes comment gravir la pyramide. D'une façon semblable, en passant d'une feuille du maître-contrôle à la suivante, nous pouvons descendre du gérant de l'usine à l'opérateur.

Nous ne pouvons exagérer l'importance pour chaque supérieur, de discuter journalièrement chacun des cercles sur son tableau avec ses subordonnés.

Tout individu dans la pyramide peut promouvoir l'action du groupe directement en-dessous de lui, en suivant cette règle.

Un gérant d'usine, qui consacre ainsi quelques minutes de son temps par jour, peut être assuré que toutes les personnes de son organisation analysent régulièrement les conditions hors de contrôle indiquées sur leurs tableaux et agissent en conséquence.

Vous avez noté que le total paraissant en rouge sur la feuille du contre-maître se retrouve sur la feuille de son supérieur, le contre-maître général. Si le contre-maître général suit la règle précédemment énoncée, le contre-maître doit savoir pourquoi il est en rouge. S'il l'ignore une première fois, il le saura sûrement la fois suivante, un supérieur ne se plaît pas à recevoir trop souvent comme réponse "Je ne sais pas".

Une grande partie de l'efficacité de ce système se trouve justement là. Personne n'apprécie les questions dans les moments de difficulté . La meilleure manière de les éviter consiste à rester en contrôle ... ou en vert: n'importe qui aime les félicitations! Un effet psychologique très net réside dans l'emploi des cercles rouges et verts.

Ce système est extrêmement flexible. Les points de vérification peuvent être changés, la structure de l'organisation modifiée, tout ce qui est nécessaire est l'addition ou la soustraction de quelques feuilles du Maître-Contrôle. Ceci peut-être réalisé en tout temps. Toutefois, ce qui existe déjà demeure valable.

Ce système s'utilise soit dans le cas d'inspection 100% ou par échantillonnage, étant donné que nous avons toujours considéré n comme le nombre inspecté. Son emploi est vaste, puisque dans toute opération de fabrication, il y a des unités et des défauts. Nous pouvons établir la marche à suivre en trois temps:

1) Sélection des points de vérification.

2) Groupement des défauts sur les feuilles du Maître-Contrôle, au niveau de l'opérateur, de façon à former une entité définie.
3) Intégration des données suivant le plan d'organisation.

Une jeune fille dispose d'environ une heure par jour, pour faire le tour de l'usine et recueillir les nombres inscrits sur les tableaux des contre-maîtres, les transférer sur les feuilles des contre-maîtres généraux, du chef de service de fabrication et du gérant de l'usine. Une fois le tour de l'usine complété, la feuille de papier utilisée par la jeune fille est remise au gérant du Contrôle de la Qualité, lui fournissant ainsi une vue d'ensemble des opérations de la fabrication en ce qui concerne la qualité.

Nous ne faisons pas de copie des feuilles du Maître-Contrôle. Chacune reste en la possession de l'individu responsable. Nous les ramassons à la fin de chaque mois quand nous les remplaçons par les nouvelles portant les nouvelles moyennes du procédé.

Nous avons le contrôle statistique de la qualité depuis 1950 et réalisâmes des améliorations spectaculaires de qualité, mais toutes de portée locale. En utilisant le système du Maître-Contrôle, nous améliorâmes la qualité dans l'ensemble de l'usine réduisant notre nombre de défauts de 40% approximativement, en un an et demi.

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GENERAL TECHNIQUES IN PULP AND PAPER MILLS

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Canada's largest industry on practically any basis for comparison is its pulp and paper industry. It is to be expected therefore that many opportunities would exist therein for application of statistical techniques. A review of the literature confirms that a diversity of techniques has in fact been used. It is just possible however that the wide diversity of techniques that have been fitted to particular requirements has itself been a deterrent to fuller application of these methods for work-a-day problems. In this paper a few specific applications will be described and it is to be understood that they represent only a sample, and probably a biased one as well, of the techniques ranging throughout the industry.

Distribution Studies

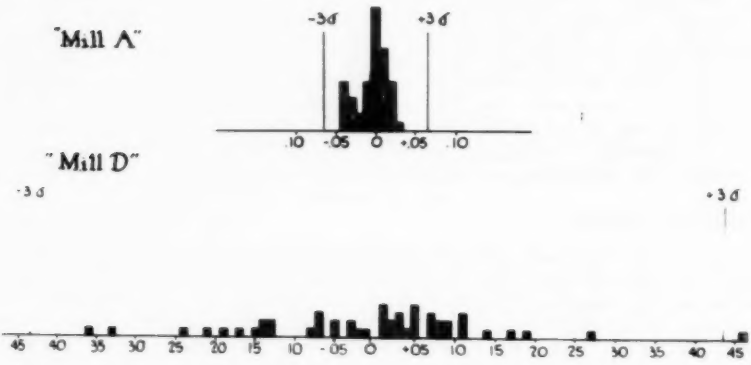
One of the earliest statistical contributions in our Canadian industry was "Engineering Data Sheet No. 261", published by the Technical Section of the Canadian Pulp and Paper Association in 1942. The data sheet gave areas under the normal curve and criteria for rejection of data. The contributor, Dr. W. Boyd Campbell of Montreal, has continued through the years to be a leading user of statistical analysis. Another publication of his, (1) involving a distribution study, concerned the folding test as commonly made in the industry. In this study the precision of the test method was evaluated and the conclusions as to the number of samples needed and to the magnitudes of the confidence intervals were drawn.

The value of a distribution study in the improvement of a test method was well exemplified in another Technical Section project (2). This time a committee was investigating the "consistency test" as practised by the members - a test that measures the solids concentration of pulp slurries handled in the mills. Fig. 1 shows the difference in precision obtained in two of the mills when using their own normal methods. When the preferred method was tried in all the mills it was found to be indeed superior and a good choice for a standard method. Fig. 2 shows the improved agreement in precision when the superior method is used by both original mills.

The advantages to be obtained from simply a visual examination of frequency distributions have been widely recognized. It is commonly used to detect personal bias in test data - where for one reason or another, the tester may have adjusted a few of his results to bring them inside the specification limits. Dirt Counting is a test that is particularly susceptible to tester error. When a given area of pulp sheet or paper is examined for number of pieces of dirt it is extremely difficult to get results properly distributed according to the Poisson Law. In counting dirt, the mind seems to resist lower than usual counts and there is an unconscious urge to count dirt of negligible size, whereas when a high count occurs, the reverse tendency slows down the count, and the true count may be underestimated. Frequent checking of results against a Poisson Distribution does much to preserve good counting and assists enforcement of standard sheets as count references. Now that we have photoelectric dirt counters, the personal element is reduced and safe

Distribution Of Consistency Results

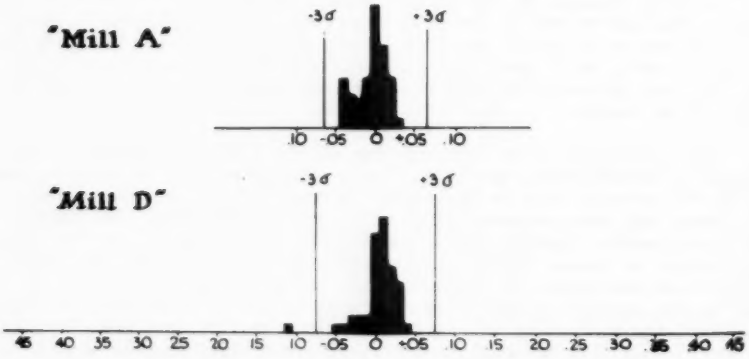
Results Obtained by two Mills When 50 Successive Determinations by Different Methods Were Made On Slush Samples of Groundwood Pulp



Difference of Result From Average Value

- Fig. 1 -

Results Obtained by Two Mills when 50 Successive Determinations Using Method of "Mill A" Were Made On Slush Samples of Groundwood Pulp



Difference of Result from Average Value

- Fig. 2 -

comparisons of results based on the Poisson Distribution can be made.

Control Chart Methods

It is a short step from distribution studies to control charts but it is a step not extensively taken in the Canadian forest industries. As reported at a recent convention (3) - "We do not use statistical quality control extensively for hour to hour process control - we do, however, use these concepts for interpreting process data collected over a day, week, month, etc., - for interpreting data collected in experimental or project work".

Of course there are many individual applications of control charts in the industry but this technique does not appear to have been picked up as effectively, perhaps in process industries in general, as in the mechanical type of industry. One reason for this is the unit sample size so prevalently used. A single sample of stock, paper, etc. is commonly taken and single or replicate tests are made on it. The result is of course subject to sampling and testing errors which may be relatively large. The concepts of sample size and sample selection so as to minimize testing errors and testing costs are not widely understood and offer opportunities in the future.

The problems caused by the "unit sample" principle have been handled in different ways in different mills. In one mill of our corporation, the control department has used analysis of variance to isolate sampling and testing errors for the tearing resistance of paper. A more precise tear value at no increased cost seems available by changing the method of sampling current production. In another place, it is reported (4) that precisions have been studied on important tests and enough sample-tests are taken at any one sampling time so as to obtain a "wider-spaced-more-reliable-point method". Still other mills accumulate the data until a rational sample size is built up and control charts are established on daily pulp qualities, average shift production, number of web breaks per week, etc. Such control charts have been useful in detecting changes in operating levels.

Instrumentation

With the advent of automatic recorders and controllers, it will be interesting to see to what extent statistical methods will be usable in process control in the future. At the present time we have large numbers of physical testing equipment in the mills. Once a knowledge of precision of tests is obtained, it can be used (5) to maintain all the instruments of a given type in calibration. Fig. 3 shows the precision of various tests commonly made. Fig. 4 shows a calibration check using reference paper on various mullen testers or "bursting strength"machines. Since the average value $\bar{\bar{x}}$ for each machine is within the calculated tolerance of the $\bar{\bar{x}}$ value, all testing machines may be considered in relative calibration.

Multivariate Assessment

Due to the number of tests made, there often arises a need for integrating several results into a single "index value". When making a beater test on pulp fibers, as many as 17 or more data may be needed to express the final test results. On a given type of pulp, each of these

TEST DATA FROM INSTRUMENT SURVEYS

Test	① No. of Values obtained on each Inst.	② Aver. Value Obtained	③ Aver. Range Obtained	④ Tolerance for Inst. Aver.	⑤ Std. Dev. of Single Value	⑥ Coef. of Variation ⑤/② x100%
Mullen 1 ply p.s.i.	10	20.5	3.4	±1.1	1.2	5.3
Mullen 2 ply p.s.i.	10	45.3	6.1	±1.9	2.0	4.4
Tear M 6 ply $\frac{1}{2}$"	4	16.9	0.73	±0.54	0.36	2.1
Densometer sec/100ml.	4	19.2	2.3	±1.7	1.1	5.9
Valley Size sec/150ml.	4	53.8	4.5	±3.3	2.2	4.1

- Fig. 3 -

WEEKLY MULLEN TESTER CHECKS

DATE: JAN. 8, 1951.

LOCATION	#	10 "POPS" SINGLE PLY	$\bar{X}$	R	REMARKS
CENT. LAB.	1	23, 24, 23, 23, 22, 24, 23, 23, 25, 24,	23.4	3	O.K.
O.P.T.	2	23, 23, 23, 22, 23, 22, 21, 23, 23, 23,	22.6	4	O.K.
O.S.P.LAB.	3	20, 24, 23, 20, 23, 21, 23, 23, 25, 23,	22.5	5	O.K.
HULL GWD.	7	23, 22, 23, 21, 21, 21, 23, 21, 21, 21,	21.8	2	O.K.
A MILL	6	23, 23, 21, 21, 22, 21, 22, 23, 21, 23,	21.8	2	Glycol Added
B MILL	5	25, 23, 22, 23, 25, 20, 24, 24, 23, 23,	23.2	5	O.K.
D MILL	10	21, 20, 22, 23, 20, 23, 23, 23, 23, 24,	22.1	4	Diaphragm Chgd.
		WEEKLY AVERAGE	22.3		
		TOLERANCE FOR INST. $\bar{X}$	±1.1		
			21.2 TO 23.4		

- Fig. 4 -

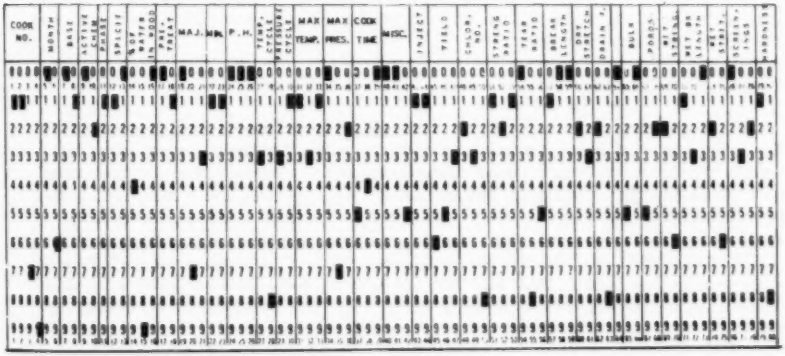
data has its own expected mean value and standard deviation. Within the scope of sampling and testing the 17 data are also uncorrelated. Under these conditions it has been found convenient to express each test result as a standard deviate in terms of its own mean and standard deviation. Squaring the standard deviates and summing over the 17 data yields a single value expressing the agreement with the 17 sets of standards. The value is distributed as Chi-Square with 17 degrees of freedom so that a single control chart can be used to determine if the beating qualities are being met.

The same technique has been used to interpret the five data obtained when pulp fibers are classified into 5 length categories. Here again we have an expected mean and standard deviation for each datum and the lack of agreement can be expressed as a Chi-Square single value. In this test the five data must add up to 100% and hence only four degrees of freedom apply to the Chi-Square value.

Simultaneous assessment of many variables when all purport to rate a single material leads to the simple question "Is it good or bad?". With such a multivariate index as the Chi-Square, the question can be answered and only when the material is rated "bad" need the individual variables be questioned. Even in this case, each item in the Chi-Square total can be assigned one degree of freedom and can be examined individually or in rational groups for significance.

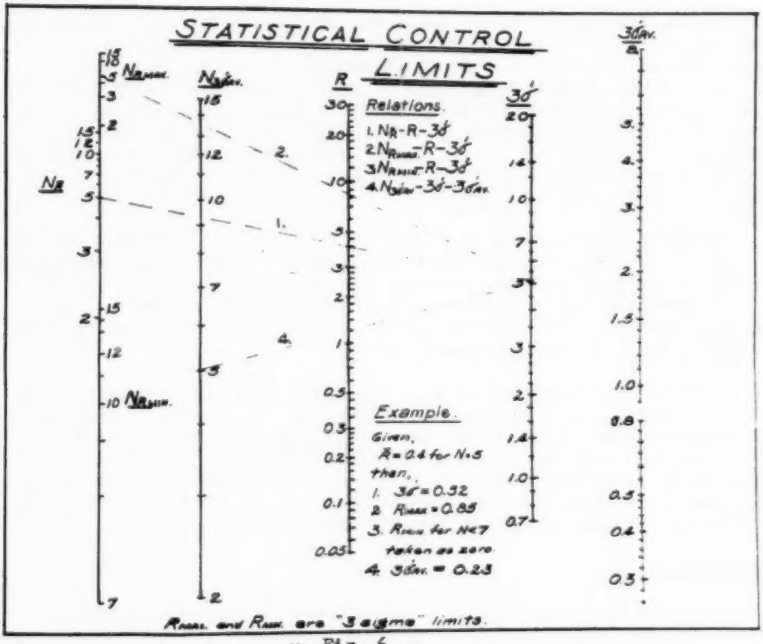
Miscellaneous Aids

Again due to the multiplicity of information handled, it is not surprising that automatic data processing techniques are coming into use. Berkyto in his 1955 convention paper (6) showed his IBM punch card used for pulp development studies. It is reproduced here as Fig. 5. Hand-sort punch cards have also been used (5).



- Fig. 5 -

In addition, some specific techniques have been developed to cope with the problem of many sample sizes as hinted at above. Although statistical slide rules are apparently available, these took the form of nomographic charts in our industry. Fig. 6 is a revised form of a nomogram of statistical relationships that appeared in reference 7 in 1949. It solves the usual relations between the population standard deviation and sample statistics.



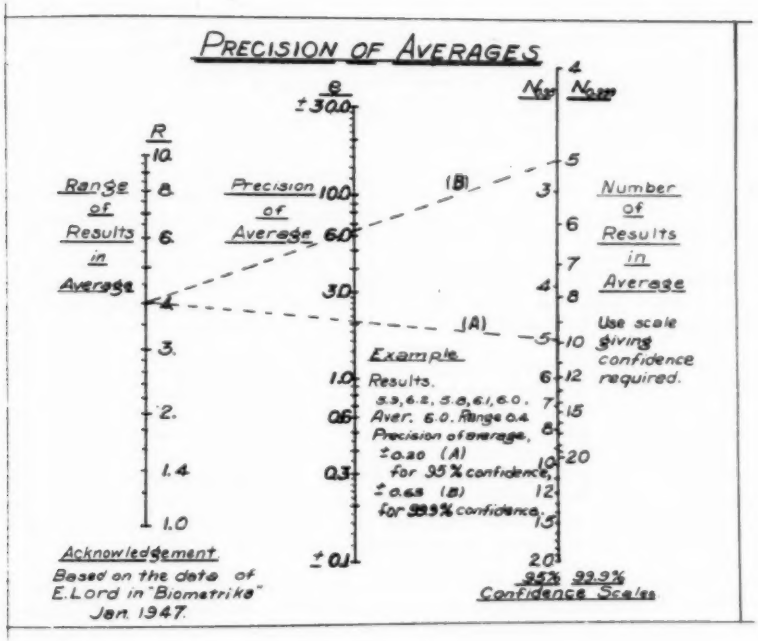
- Fig. 6 -

Another nomographic chart Fig. 7 solves the problems of estimating confidence limits based on the observed range in a single sample. This latter chart is convenient for checking the adequacy of information from short term process studies.

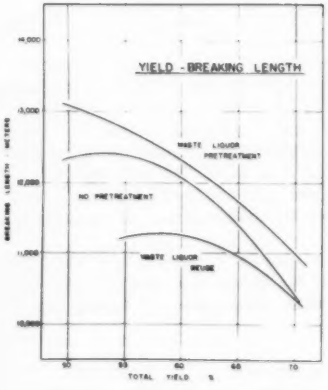
Advanced Techniques

In this category, regression studies will be mentioned since the choice of proper regression models and the computational requirements are real hurdles to full use of these methods. Perhaps due to the long use of essentially a natural raw material, wood, and the number of process operations performed, the strong simple linear correlations have become well known and new significant gains are being made through multiple correlation and non-linear studies. This field is somewhat handicapped due to the length of computations involved, but Berkyto with his punch cards (6) has shown how this work load can be reduced somewhat by machine processing. Examples of his non-linear regression curves are shown here as Figs. 8 & 9. Typical examples of multiple correlation studies are the investigations, of the contribution of individual pulp constituents in final pulp qualities, and of the relative effects of liquor strength, cooking time, and cooking temperature, on the softness of chemically cooked pulps.

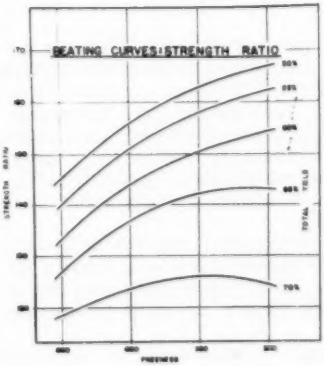
Mixing, agitation, and regulation are important process operations to us. Testing the efficiency of these operations, presents interesting statistical opportunities. In one mill a comparison of regulating devices was made and two technicians were assigned to do the test work.



- Fig. 7 -



- Fig. 8 -



- Fig. 9 -

All samples before and after the regulators were taken in duplicate and each technician performed his tests in quadruplicate so that small changes in test levels could be detected. In another mill when checking agitation in a storage tank, single test results were obtained hourly over a 24-hr. period on entering and leaving stocks. Variances were established by successive difference to minimize trends and the entering-to-leaving variance ratio was tested by a standard "F-test". Both of these applications used concepts originally described in an article by Beaudry (8) in 1948.

The analysis of variance technique and statistically designed experiments are becoming more appreciated in research and development activities. Reference was made above to its use in improving the sampling procedure when testing the tearing resistance of paper production. A similar study revealed that replicate test samples from a single kraft cook were inefficient in measuring the general process level due to large cook-to-cook variations and therefore that single samples from separate cooks were to be preferred.

On one trial, the effectiveness of a certain wetting agent in our sulphite cooking process was being rated. Mill production cooks each using 50 tons of chips were made with and without the additive under mill conditions with three acid strengths and two cooking times. The series was replicated once at a one-week interval for a total of 24 mill production cooks. The pulp produced was tested for seven operating and quality criteria. The test program confirmed mill practices with acid strengths and cooking times and concluded that the wetting agent produced no economic effect on the operating and quality criteria.

In passing it is mentioned that many development problems are of a sort that a new modification of the analysis of variance method would be desirable. In many experiments, variability itself should be studied under various process combinations. Whereas analysis of variance shows changes of level under various combinations, it also assumes equal residual cell variances. It is known, however, that each new procedure, or new equipment, has its own effect on the variability and it would often be useful if a new "analysis of variance" technique were available to isolate the variability in terms of main effects and interaction effects.

Another difficulty arises in say three factor experiments if more than one of the first order interaction terms are found to be significant. Testing of the main effects may apparently be approached in two dubious ways. Some authorities recommend splitting the test data so as to lose the significant interactions whereas other authorities frown on this procedure possibly due to the loss of power. If the data are not split, a linear combination can be built up to test the main effects but it seems that the number of degrees of freedom of such a combination is uncertain.

Statistical applications in the pulp and paper industry are hampered by the two difficulties noted. If solutions to these are available, the writer would appreciate hearing of them so that some note of these can be made in our industry literature.

Summary - A wide range of statistical techniques are being used in Canadian pulp and paper mills. Control charts are not however generally used for on-the-spot process control and a trend towards instrumentation may reduce possibilities for these. For some specific problems, developments in statistical theory are being awaited.

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STATISTICAL TECHNIQUES IN PAPER TESTING

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This discussion will be limited to consideration of some of the statistical problems of evaluating pulp and paper testing methods and will be concerned only incidentally with the use of the methods, say for process control. Although it is realized that the variable nature of the material measured provides some unusual problems in paper testing, it is not believed that the problems are unique, nor that what needs to be said about paper testing is very much different from what needs to be said about testing in general.

Certain peculiarities observed in some paper testing results have led to an application of range theory which suggests some interesting possibilities for supplementing other well known range techniques. This application, which will be described, is most likely to be useful under conditions such as:

1) When chronology has not been maintained or is unimportant, as in an analysis of variance

2) When measurements are arranged dimensionally, as well as chronologically, as in measurements along and across material in sheets or strips

3) When the "assignable cause" of non-normality is likely to be due to non-independence or serial correlation of results, as when, unknowingly, the same material has been measured repetitively.

It has been known for some time (1) that when paper specimens are made very small and taken very close together, the variation within small subgroups will be excessively small compared to the fluctuations normally observed in a roll of paper. Shewhart provides a lengthy discussion of the distribution of the range and gives enough data (2) to permit comparing observed ranges of extremely small subgroups with the expected distribution. This source of theory was adequate to permit some observations on optimum spacing of measurements of paper (3). By making use of much more complete tables of the distribution of the range, (4), it has been possible to extend that work considerably and to study problems involved in determining precision of test methods.

Precision of a test method is, quite generally, taken to mean the extent to which independent, repeated measurements of a quantity cluster about their average. It is expressed in terms of the standard deviation and, since the greater the clustering, the smaller the standard deviation, precision is inversely related to the size of the standard deviation.

Precision is an inherent property of the method, which is changed only when the method is changed. It is, therefore, necessary to have a very complete definition of the steps, or process, involved in carrying out the method. Thus, within one laboratory, precision may apply to a measurement process consisting of a single instrument-operator combination. This process must be "controlled" in a statistical sense, that is, all variation must be random, or, all "assignable causes" of variation must have been identified and removed.

The study of within-laboratory precision will involve an investiga-

tion using control charts or a designed experiment followed by an analysis of variance to determine whether different instruments, different operators, or the passing of time does increase the over-all variation significantly.

A typical example is provided in an experiment to compare two different makes of brightness meter used to measure the brightness of pulp or of the finished paper sheet. A single large homogeneous sample of bleached kraft slush pulp was obtained. Four operators prepared 24 handsheets apiece, three at the beginning of each hour for eight hours. Five readings on one type of brightness meter were made on each handsheet. Then another similar set of readings was made using the second type of brightness meter.

There were a number of very interesting bits of information about precision obtained from the analysis of variance of these data. However, attention will be limited to the degree of agreement within the five repetitive measurements on each handsheet. There were 96 sets of five measurements for each type of meter. The meters will be designated Meter A and Meter B.

One of the assumptions on which the analysis of variance is based is the homogeneity of variances within sets. The formal analysis of variance does not provide any test for this homogeneity. One convenient way of making this test is to use a control chart for ranges of the sets. For Meter A, all 96 ranges were in control. For Method B, however, five ranges were out of control. This, of itself, would have been of some concern except that another even greater inconsistency seemed to exist. It was noted that the within-set variance for Meter B was less than a tenth of the within-set variance of Meter A.

There is a technical reason that might help to explain this divergence. This reason is that the sample aperture of Meter B is much larger than the sample aperture of Meter A. Therefore, Meter B "sees" a much larger area of the sheet and, in effect, averages brightness over this area. There was also, however, the suspicion that, like other paper test data studied before, these data from Meter B might not be independent measurements. An indication of non-independence would be the occurrence of many more sets than one would expect in which the range was zero or was very small.

The range control chart does not provide a means for making a check of this condition. In the first place, for sets of size five, the lower control chart limit is zero. In the second place, although a count of runs above and below average might be considered, there is no completely satisfactory way of arranging these data chronologically. Where the chronology is satisfactorily preserved (i.e., within the work of one analyst), the total number of observations is inadequate for this latter test.

A comparison of the theoretical and observed distribution of ranges of sets of five was, however, perfectly feasible. Therefore, reference was made to Pearson's table of the probability integral of the range (Reference 4) and a table of the expected frequency of ranges was constructed. Pearson's table is entered for sample size five and for the ratio of the range to standard deviation to obtain the cumulative percent of the total ranges expected to be found at each ratio. The standard deviation is known, in the example, from the analysis of variance.

Ranges were used at measurement intervals of 0.2 brightness units. The resulting expected number of ranges at each interval is given in the column headed "Expected" in the table below. The actual number of ranges at each interval was counted and reported as "Observed".

TABLE I. Meter B. Expected and Observed Distribution of Ranges of Sets of Five Repetitive Tests.

Range	Expected	Observed
0.2	17	37
0.4	49	38
0.6	26	14
0.8 and over	4	7
	96	96

A standard Chi-square test may be applied to these data.

$$\chi^2 = (37-17)^2/17 + (38-49)^2/49 + (14-26)^2/26 + (7-4)^2/4$$

$= 33.8$, with two degrees of freedom, which is significant beyond the 0.001 level.

The reason for this significant departure from expectation is not hard to see. There are many more small ranges than one would expect. When the results for the individual analysts were reviewed, it was found that one had two zero ranges and 13 ranges of 0.1, out of a total of 24 ranges. Two other analysts showed an almost equal tendency to get an excessively large proportion of the smaller ranges. The fourth analyst showed no such discrepancy.

This result is made all the more convincing by the fact that a similar analysis for Meter A turned up no significant difference between the expected and observed distribution of ranges, as shown in Table II.

TABLE II. Meter A. Expected and Observed Distribution of Ranges of Sets of Five Repetitive Tests.

Range	Expected	Observed
0.45	1	1
0.95	19	18
1.45	38	36
1.95	25	31
2.45	10	9
2.95	3	1
	96	96

$\chi^2 = 3.03$, with four degrees of freedom, which is not significant at the 0.05 level.

Returning to the problem of Meter B, it appears, then, that there

are a number of things peculiar about the performance of the test. The fact that the within variability is very small may be explained only partially by the larger sample aperture. There appear to be many more ranges of very small size, particularly of 0.1 brightness units, than there should be. This is accounted for, largely, by the work of one of the analysts who had a decided bias in favor of ranges of 0.1. The bias is apparent, however, in the work of two of the other analysts as well. It is, perhaps, more than a coincidence that the analyst with the poorest showing in the distribution analysis was also the one who had two of the largest out of control ranges. The next poorest showing in distribution of ranges was by another analyst who had two points out of control on the high side on the range control chart. The third poorest agreement in distribution of ranges was by the analyst who was responsible for the fifth out of control point ! The fourth analyst had a clear score in all respects.

The net result, of course, is to make all the measurements from Meter B suspect. Apparently, further training in the use of this type of meter is advisable. A re-run of the experiment would be necessary to come up with trustworthy precision data.

It is not known exactly what caused this tendency to obtain more small ranges than expected. It may be due to the fact that when the over-all difference is not large, greater care must be exercised in attempting to discriminate between small differences on the scale. It may be due to the fact that the relationship between the aperture size and the specimen size is such that a new measurement was not obtained upon repetition, i.e., all that was reported was a re-reading of the same measurement. Care must always be taken in making repetitive measurements to get really independent readings. That is, the specimen must be removed and replaced in the instrument, or be completely reoriented. Or, the instrument must be completely thrown out of adjustment and readjusted so as to get a series of really independent results.

Something about the way three out of four of the analysts used Meter B interfered with the expected distribution of the reported results. The test for conformance of the observed distribution of ranges with the theoretical provided a very sensitive way of pointing out that the condition existed. Thus, it appears to be a very useful supplemental tool for the statistical analysis of test results.

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SIMPLICITE ET DIFFICULTES DE LA STATISTIQUE

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Ayant eu à faire il y a quelque temps une conférence sur les méthodes statistiques appliquées à la recherche industrielle, je me bornai à exposer des idées générales sur les plans d'expérience et à commenter quelques exemples très simples: le public était nombreux, hétérogène, peu ou pas averti de ces questions. A la sortie, l'un des auditeurs s'étonna que je n'avais pas parlé de l'analyse de la variance (je n'avais même pas prononcé ces mots): C'est tellement simple et spectaculaire me dit-il, ou à peu près -on écrit les sommes, les sommes des carrés, les carrés des sommes - on additionne ou l'on retranche -on consulte enfin la table de Snedecor et l'on conclut en toute tranquillité.

Cette façon d'envisager l'analyse statistique me fit penser à ces problèmes de mots croisés ou à ces devinettes dont l'énoncé figure aux premières pages des hebdomadaires et dont la solution se trouve à la dernière page, imprimée à l'envers. Si je n'avais pas parlé d'analyse de variance, c'était volontairement, ne voulant pas faire croire à un public sans défense qu'il existe des mécanismes arithmétiques apportant des réponses définitives à des problèmes souvent fort complexes. Dans le comportement des gens qui viennent à s'intéresser aux méthodes de la statistique, il y a généralement, succédant à une attitude de méfiance, une période d'enthousiasme. C'est celle-ci -que traversait sans doute mon interlocuteur -qu'il convient à mon avis de dépasser- et ce sont quelques réflexions sur les difficultés que masque l'apparente simplicité des méthodes statistiques que je voudrais essayer d'exposer.

Les applications industrielles de la statistique sont généralement rassemblées sous trois rubriques:

- les contrôles de réception
- les contrôles en cours de fabrication
- la recherche qui comprend regression, corrélation et plans d'expérience.

Les contrôles en cours de fabrication sont généralement traités en premier lieu, bien que ce ne soient pas les plus faciles au point de vue interprétatif. Les applications à la recherche, dans leur aspect "analyse de la variance" sont parmi celles qui soulèvent les difficultés les plus sérieuses, bien qu'elles semblent présenter un vif attrait pour ceux qui ont commencé à y goûter. En fait, l'ordre que nous avons choisi est celui qui va du plus simple et du plus sûr au plus difficile et au plus incertain.

Dans tous les cas on porte un jugement, ou l'on prend une décision à partir d'un échantillon; on se donne à priori, ou l'on calcule à postériori,des "risques" ou des "intervalles de confiance" qui mesurent l'incertitude du rattachement de l'échantillon à un ensemble plus nombreux, qu'on est même

souvent amené à considérer comme infiniment nombreux, dit ensemble, ou population de référence. Une étude attentive de l'efficacité des plans de contrôle ou de recherche permet de minimiser les risques, ou, pour des risques donnés, d'économiser des observations, ou encore de minimiser le coût d'une suite d'opérations aussi bien définies que possible. Mais le problème qui nous préoccupe n'est pas là: il concerne essentiellement la nature et même l'existence de la population de référence.

Contrôles à la réception.- Dans ce domaine, il y a peu ou pas de difficultés. Lorsqu'il s'agit d'objets distincts, constituant des lots bien définis, l'échantillonnage simple avec classement en bon ou mauvais est absolument comparable au tirage (avec ou sans remise) de boules dans une urne contenant des boules blanches et noires dans des proportions données. Il n'y a pas d'ambiguïté sur la population de référence, qui est constituée par l'ensemble de tous les objets du lot, ou symboliquement par une urne de composition bien définie. Des difficultés peuvent se présenter dans l'éxécution matérielle de l'échantillonnage (qui doit être fait "au hasard") lorsque les objets ne peuvent être prélevés commodément, ou lorsque l'épreuve de classement est destructive - ou lorsque le lot soumis à la réception est constitué, non pas d'objets distincts (pièces usinées) mais d'une matière quasi-continue (grains, poudre, liquide, etc...)ou encore lorsque la distinction entre bon et mauvais n'est pas très nette. Ces différentes situations peuvent compliquer l'éxécution des opérations de réception, mais elles ne modifient pas la nature même du problème.

Un double échantillonnage, ou un échantillonnage progressif, n'introduisent aucune difficulté de principe. Il arrive aussi que l'échantillonnage puisse s'effectuer à plusieurs niveaux: par exemple, les objets sont rassemblés dans des caisses, plusieurs caisses sont réunies dans un emballage plus important, et le lot entier est constitué de plusieurs de ces emballages. On peut imaginer divers plans d'échantillonnage, suivant l'efficacité que l'on recherche et surtout suivant la nature des renseignements que l'on désire obtenir: jugement sur le lot entier, ou jugement sur les divers sous-ensembles inclus dans le lot. Il y a alors plusieurs populations de référence, mais en nombre fini, et chacune a une existence propre.

Lorsque les objets échantillonnés font l'objet de mesures le problème n'est pas non plus modifié dans son essence. Il faut simplement faire une hypothèse sur la loi de distribution des mesures; l'hypothèse la plus généralement admise, et que nous ne discuterons pas, est que cette distribution est normale.

Ainsi, lorsque dans un contrôle à la réception on introduit les notions de "risque de l'acheteur" et "risque du vendeur", la signification de ces risques est parfaitement claire. Si le plan d'échantillonnage adopté comporte un risque de l'acheteur égal à 0,05, ce dernier sera amené à la longue -c'est-à-dire à la suite de l'inspection d'un grand

nombre de lots- à accepter, dans une proportion voisine de 5%, des lots qu'il aurait refusés s'il les avait inspectés à 100%

Contrôles en cours de fabrication.- Lorsqu'un contrôle de réception s'effectue par échantillonnage progressif (ou séquentiel), une décision peut être prise à un instant quelconque, au fur et à mesure de l'arrivée des objets qu'on prélève à la suite. Une situation apparemment analogue, mais foncièrement différente, se présente dans les contrôles en cours de fabrication, par "cartes de contrôle". Afin d'éliminer toute hypothèse sur la nature des distributions (cet élément n'intervenant d'ailleurs pas dans le point de vue où nous nous plaçons) nous envisagerons tout d'abord le cas d'une carte de contrôle par "bon ou mauvais" (qui n'est généralement pas la carte la plus efficace). Au lieu de parler des risques de l'acheteur et du vendeur, on parlera du risque de régler la machine lorsqu'elle fonctionne correctement, et du risque de ne pas la régler alors qu'il le faudrait. Imitant la terminologie des contrôles de réception, on dit encore qu'il y a le risque de refuser et le risque d'accepter le réglage. La carte de contrôle est avant tout basée sur le premier risque (généralement, limites de contrôle à 0.002 % et limites de surveillance à 0.05 %) - l'étude de son efficacité fait intervenir le deuxième risque.

Il y a similitude de langage, mais, répétons-le, les problèmes sont foncièrement différents. Dans un contrôle en cours de fabrication, la population est en quelque sorte en création permanente. Parler d'une population de référence "instantanée" qui serait définie par la probabilité pour le complexe (machine, matières premières, équipe, etc...) de produire à l'instant considéré un objet mauvais, peut être une attitude commode pour le théoricien, mais elle ne paraît pas s'accorder parfaitement avec les préoccupations du fabricant. D'ailleurs un prélèvement n'est jamais instantané, puisqu'il comprend plusieurs objets fabriqués à la suite; même dans le cas d'une fabrication bien réglée, des objets voisins peuvent se ressembler plus étroitement que des objets pris assez loin les uns des autres, ce qui introduit des complications supplémentaires.

Une tranche de fabrication importante d'une machine fonctionnant correctement constitue sans doute une population de référence bien définie, qui se perpétue, identique à elle-même, au cours du temps. Il est donc tout à fait correct de dire que "dans l'hypothèse où la machine reste bien réglée" les points ne sortiront des limites de contrôle que dans la proportion prévue par le risque de "refuser le réglage", 2/I.000 par exemple; cette machine subira à tort un réglage en moyenne deux fois par groupe de I.000 points inscrits sur la carte: c'est une faute de manoeuvre suffisamment peu fréquente pour qu'on ne se préoccupe pas de ses conséquences.

La situation est tout autre lorsque la machine vient à se dérégler. S'il s'agit d'un déréglage brutal (rupture d'une pièce), on passe brusquement d'une population de référence à une autre; mais, contrairement à ce qui arrive dans les contrôles de réception, où l'on passe en le sachant d'un lot au

lot suivant, on ne connaîtra généralement pas l'instant de ce passage, et l'on n'aura pas la possibilité de séparer immédiatement les populations (à moins que l'effet du déréglage soit énorme, ou que l'on ait repéré aussitôt la pièce cassée -auquel cas il n'est pas besoin de consulter la carte de contrôle). L'effet sur la carte sera que la proportion de points hors limites dépassera 2/I.000; la carte risque de ne refléter le déréglage que longtemps après qu'il s'est produit si le déréglage n'est pas très important, et si pour le contrôleur le "reflet du déréglage" est uniquement l'apparition d'un point hors limites. Cela ne sera peut être pas très grave (par exemple si la machine est plus précise qu'il n'est nécessaire relativement aux caractéristiques des objets qu'elle fabrique) mais ce n'est pas le point de vue où nous nous plaçons.

Si le déréglage se produit peu à peu, comme c'est le cas le plus fréquent (usure progressive des pièces de la machine) la situation est plus sournoise. La population de référence se modifie alors de façon continue: son image serait celle d'une urne perdant peu à peu ses boules blanches, lesquelles seraient aussitôt remplacées par des boules noires. Si plusieurs personnes viennent, les unes après les autres, puiser dans cette urne à composition évolutive, il faudra sans doute attendre assez longtemps pour que l'une d'elles s'aperçoive qu'on n'a plus affaire à la même urne: c'est en fait ce qui se passera si l'observation de la carte de contrôle ne porte que sur le dernier point qui y a été inscrit.

Enfin, il ne faut pas exclure le cas où la machine, après s'être quelque temps déréglée, retrouve d'elle-même un fonctionnement correct: cette fois l'urne de référence perd des boules noires lesquelles sont remplacées peu à peu ou d'un seul coup par des boules blanches. Cette situation n'est pas si invraisemblable qu'il paraît à première vue. Elle se produit lorsque ce qu'on a appelé "déréglage", c'est-à-dire variation non aléatoire d'une ou plusieurs caractéristiques des objets fabriqués, provient d'une "tendance" dans les propriétés d'une matière première continue; cette tendance peut présenter des auto-régulations souvent imprévisibles. Nous en avons des exemples fréquents dans l'industrie du tabac où une machine à cigarettes, qui débite I.500 unités à la minute, est alimentée par un flux continu de tabac haché dont les propriétés ont pu, pendant un temps plus ou moins long, être modifiées par les opérations antérieures. Un réglage intervenant dans de telles circonstances peut aller à l'encontre du but recherché.

Revenons sur l'interprétation que l'on peut donner d'un point venant s'inscrire en dehors des limites d'une carte de contrôle. Nous considérerons maintenant une carte de contrôle de la moyenne, à partir d'échantillons de n unités.La limite supérieure de contrôle a été tracée à $3{,}09\ \sigma/\sqrt{n}$ de la moyenne théorique m, de sorte qu'il n'y a qu'une chance sur I.000 pour qu'un point vienne dépasser cette limite. Le rang moyen d'arrivée du premier point au delà de cette limite, dans l'hypothèse où la population de référence reste inchangée (population normale m, σ) est évidemment I.000. Un calcul

simple montre d'autre part qu'il n'y a que 5 chances sur I00 pour que ce point ait un rang inférieur à 52. Si donc le premier point hors limite arrive avant le 52/ème prélèvement, on peut conclure, sous le risque 0,05, que la population de référence n'est plus celle sur laquelle on comptait, et effectuer un réglage. Mais si le rang d'arrivée est nettement supérieur à 52, le point considéré peut fort bien ne correspondre à rien d'anormal.

Supposons maintenant qu'à un instant donné la moyenne de la population de référence soit passée de m à $m + 0{,}5\ \sigma/\sqrt{n}$. Le calcul montre que le rang moyen d'arrivée du premier point hors limite supérieure est 208 et qu'il n'y a que 5 chances sur I00 pour que ce premier point arrive avant le II/ème prélèvement suivant le déréglage; il est donc très probable qu'on attendra assez longtemps avant d'observer sur la carte ce point d'alerte. Le tableau ci-dessous donne, en fonction du déréglage de la moyenne, le rang moyen $\bar{n}$ d'arrivée du premier point hors limite supérieure, et le rang $n_{0,05}$ qui a 95 chances sur I00 d'être dépassé.

Déplacement de la moyenne	$\bar{n}$	$\bar{n}_{0,05}$	Déplacement de la moyenne	$\bar{n}$	$\bar{n}_{0,05}$
$m + 0{,}0\ \sigma/\sqrt{n}$	I.000	52	$m + 0{,}7\ \sigma/\sqrt{n}$	II9	6
$m + 0{,}I$ "	7I4	37	$m + 0{,}8$ "	90	5
$m + 0{,}2$ "	526	27	$m + 0{,}9$ "	70	4
$m + 0{,}3$ "	385	20	$m + I{,}0$ "	55	3
$m + 0{,}4$ "	278	I4	.....	.....	...
$m + 0{,}5$ "	208	II			
$m + 0{,}6$ "	I56	8	$m + 3{,}09\sigma/\sqrt{n}$	2	-

En définitive, la carte de contrôle donne des renseignements sur une population de référence qui est ou peut être en évolution. Comme personne n'est maître de l'avenir, il faut bien admettre -et cela est généralement raisonnable- qu'une décision d'intervention à un instant donné ne s'avérera pas inopérante ou néfaste par suite d'une réaction inattendue de la machine ou des matières premières. Mais dans l'examen d'un processus évolutif, il est tout à fait insuffisant de se borner à exploiter le renseignement présent sans utiliser les données antérieures. La carte de contrôle doit, après chaque prélèvement, être lue et interprêtée dans son ensemble, en tenant compte à la fois des limites de surveillance et de contrôle. L'examen des tendances qui se révèlent dans le nuage de points est au moins aussi instructif que la place du dernier point inscrit: on évitera ainsi d'attendre trop longtemps avant de porter remède à une situation qui se dégrade peu à peu. Mais pour cela il ne faut pas seulement que le contrôleur sache écrire et lire, il faut encore qu'il soit intelligent. Naturellement cette interprétation rapide et forcément approximative de l'ensemble des points déjà inscrits sur la carte, en vue d'une décision immédiate, peut heureusement être complétée par une étude statistique précise des cartes journalières, hebdomadaires, mensuelles, etc ...

Dans le contrôle en cours de fabrication, les "risques" n'ont pas la même signification concrète que dans le contrôle de réception. La carte de contrôle, servie et interprêtée intelligemment, permet de "faire pour le mieux" avec des moyens économiques. Les résultats de cette action pourront s'exprimer de façon plus précise à l'occasion de la réception, dans l'usine même ou chez le client, des lots d'objets ainsi fabriqués.

Recherche industrielle.- Nous nous limiterons aux plans d'expérience, laissant de côté ce qui touche à la regression et à la corrélation.

Une expérience est organisée pour comparer plusieurs traitements, ou plusieurs combinaisons de traitements, dont l'une sert généralement de témoin. Les combinaisons adoptées correspondent à un plan de l'un des types bien connus "plan factoriel", "blocs", "carré latin", etc ... L'analyse de la variance permet de tester si différentes comparaisons, convenablement choisies (qui correspondent aux "effets principaux" et aux "interactions") peuvent être considérées comme "significatives". L'analyse dérive d'un "modèle linéaire", choisi à priori, de la forme

$$x_{ij\ldots} = m + a_i + b_j + \ldots + (ab)_{ij} + \ldots + e_{ij\ldots}$$

comportant moins de paramètres qu'il n'y a d'observations. Les a, b, ... correspondent aux "effets principaux", les (ab)... aux interactions du premier ordre, et ainsi de suite. Nous n'insisterons pas sur le caractère assez conventionnel du modèle. Ce qui nous préoccupe, c'est de savoir dans quelle mesure, et à quoi sont généralisables les conclusions de l'analyse. La réponse à "dans quelle mesure?" est dans une certaine mesure (si l'on peut dire) exprimée par le seuil de probabilité adopté dans l'application du test F de Snedecor ou du test t de Student-Fisher; au seuil 5 % par exemple, on n'a que 5 chances sur 100 de conclure à une différence réelle, alors que cette différence n'existe pas: il s'agit d'un risque de "I/ère espèce", le risque de 2/ème espèce devant généralement être ignoré. La réponse à la question "à quoi les conclusions s'appliquent-elles?" met à nouveau en cause la notion de population de référence.

Dans une expérience bien organisée, les facteurs susceptibles d'influencer les résultats sont, soit maintenus constants, soit contrôlés (et représentés par des paramètres dans le modèle linéaire) soit affectés au hasard (ou comme on dit "randomisés"). Ils interviennent alors dans le terme d'erreur $e_{ij\ldots}$ du modèle et c'est sur ce terme que nous devrons porter notre attention. Une hypothèse fondamentale de l'analyse de variance est que les $e_{ij\ldots}$ sont des éléments extraits au hasard d'une même population normale de moyenne nulle et ayant une variance σ^2 bien définie dite "variance de l'erreur". La population de référence ne peut donc être que cette population normale; pour que l'expérience constitue une image fidèle de ce qui se passe dans le cadre élargi d'une fabrication industrielle présente ou à venir, - c'est-à-dire pour que ses conclusions soient généralisables - il faut que l'erreur rassemble , en quelque sorte , tous les

facteurs aléatoires susceptibles d'intervenir spontanément dans cette fabrication -et tous les facteurs systématiques de faible importance qui n'ont été ni maintenus constants, ni contrôlés. Il est donc particulièrement intéressant de s'assurer que la variance de l'erreur dont on a une estimation par la variance résiduelle de l'analyse de variance, correspond à quelque chose de suffisamment bien défini, c'est-à-dire représente un ensemble de circonstances aléatoires reproductibles. On peut faire cette épreuve chaque fois qu'on dispose de plusieurs estimations indépendantes de la variance de l'erreur. Or les conclusions auxquelles on arrive dans ce cas ne sont pas toujours très rassurantes: nous en donnerons trois exemples.

I/er Exemple.- Etude sur le rendement des scies.- Cette étude est due à trois auteurs suisses, MM. J. Zehnder, A. Weber et A. Linder; elle a été publiée dans les "Annales de l'Institut Fédéral de Recherches Forestières" (Zurich, 1951).

L'expérience comporte de nombreux facteurs combinés très ingénieusement. Six sortes de scie passe-partout (en réalité 3 sortes dont chacune est répétée 2 fois) sont combinées en carré latin 6 x 6 avec six équipes de scieurs et six essences d'arbre (en réalité 3 essences, chacune figurant écorcée et non écorcée). Douze carrés latins ainsi constitués sont les éléments d'un dispositif factoriel où sont représentés 3 diamètres d'arbres (petits, moyens et grands), deux emplacements sur l'arbre du tronc soumis à sciage (base et sommet), et deux journées de travail (la deuxième après réaffutage). On dispose d'un ensemble complexe de 36 x 12 = 432 mesures (temps de sciage) qui peuvent être analysées soit globalement, soit en plusieurs groupes séparés. Nous citons ci-après les conclusions des auteurs:

"1- La troisième sorte de scie est toujours plus rapide "que les deux autres.
"2- L'analyse ne fournit aucun indice certain relativement "à une différence entre les deux premières sortes.
"3- Les exemplaires d'une même sorte ne se distinguent pas "le premier jour.
"4- Après aiguisage, le second jour, les 2 séries de la "2/ème sorte sont de rendement différent.

"La tentative de traiter les 432 données en bloc a échoué "par le fait que les 12 variances résiduelles ne sont pas ho-"mogènes et qu'il est impossible de trouver une variance résiduelle valable pour les 432 données à la fois".

Les 12 variances résiduelles, chacune comportant 20 degrés de liberté, sont données dans le tableau de la page suivante.

Le test de Bartlett, appliqué à ce groupe de variances, donne une valeur de χ^2 égale à 123,6, avec 11 degrés de liberté, alors que la valeur de χ^2 au seuil 0,01 est de 24,725.

Que serait-il arrivé si l'on avait cependant analysé les données globalement? On aurait effectué une analyse de

variance apparemment très savanteet minutieuse, avec beaucoup de termes d'effets principaux et d'interactions diverses. Mais, pour tester leur signification, on aurait utilisé une variance résiduelle unique qui, d'après ce qui précède, n'aurait rien représenté de valable. Quelles qu'aient pu être les réponses données par les tests, il aurait été imprudent de leur accorder confiance. L'analyse séparée des I2 "sous-expériences" est moins "spectaculaire", mais les conclusions sont beaucoup plus sûres. D'autre part, ces analyses attirent l'attention sur le fait que le rendement des scies peut être influencé, de façon importante, par des facteurs inconnus, et cela évitera de prendre des décisions trop hâtives ou trop catégoriques.

Jour	Diamètre	Extrémité	Variance résiduelle
I	P	I	I05,90
I	P	S	65,24
I	M	I	I08,73
I	M	S	6I,45
I	G	I	340,84
I	G	S	320,I5
2	P	I	73,78
2	P	S	27,69
2	M	I	I07,03
2	M	S	46,65
2	G	I	88I,68
2	G	S	69,I7

2/ème Exemple.- Etude de l'influence de cinq facteurs dans un essai de flottation.- Cette étude est due à M. Adrian C. Dorenfeld et a été publiée dans "Mining Engineering" (N° I2 Décembre I95I). Chacun des 5 facteurs (dimension de maille, pH, taux de xanthate, taux de cyanure de sodium, taux de mousseur), est essayé à deux niveaux. Les facteurs sont combinés factoriellement sans répétition: il y a donc au total 25 = 32 mesures (rendement en métal exprimé en %).

Comme il n'y a pas de répétitions, l'erreur doit être estimée à partir des interactions d'ordre Ie plus élevé. Une première étude montre que les carrés moyens relatifs à l'interaction du 4/ème ordre, aux 5 interactions du 3/ème ordre et à 9 sur I0 des interactions du 2/ème ordre sont du même ordre de grandeur; en les groupant dans un terme résiduel, celui-ci est égal à 43,4I avec I5 degrés de liberté. Partant de cette première estimation de la variance de l'erreur, on constate que l'effet de l'un des facteurs (P) est considérable: le carré moyen correspondant à P dépasse à lui seul la somme des carrés moyens relatifs aux 4 autres effets principaux et aux II interactions qui ont été conservées.

Après avoir reconnu l'existence de cet effet (qu'on peut

d'ailleurs constater sans calculs statistiques), on a scindé les résultats en deux groupes de chacun I6 mesures, l'un correspondant au niveau élevé de P et l'autre au niveau bas. L'analyse du premier groupe de mesures montre que les interactions du I/er ordre ne sont pas significatives par rapport à celles d'ordre plus élevé; en bloquant dans un terme résiduel les sommes de carrés afférentes aux interactions de tous ordres, on obtient une estimation de la variance de l'erreur égale à 20,34 avec II degrés de liberté. Dans le groupe de mesures correspondant au niveau bas de P, on est conduit à conserver l'une des interactions du I/er ordre, et l'on trouve une estimation de la variance de l'erreur égale à 64,22, avec I0 degrés de liberté.

Les deux estimations de σ^2 ainsi séparées sont significativement différentes. En renonçant à analyser l'ensemble des 32 mesures, et en traitant séparément les deux groupes de I6 correspondant à deux niveaux fixes du facteur P, on perd l'information sur les interactions de P avec les quatre autres facteurs, -mais en fait on obtient des résultats plus précis et sans doute plus valables sur le mode d'action de ces quatre facteurs.

3/ème Exemple.- Essais sur la gélivité des bétons.- Avant d'entreprendre une expérience permettant de déterminer les facteurs qui influent sur la résistance au gel des bétons, on a procédé à une étude préliminaire portant sur la dispersion des mesures de résistance à la compression.

A partir de 5 ciments (A, B, C, D, E,) on a réalisé un certain nombre d' "essais" (I5 ou I6) comprenant 4 cubes provenant d'une même gâchée. La résistance à la compression de deux d'entre eux (dits "témoins") a été mesurée; la résistance des deux autres (dits "gelés") a également été mesurée après application d'un cycle de gel -dégel. Chaque essai "témoins" et chaque essai "gelés" de chaque ciment a fait l'objet d'une analyse de variance séparant la dispersion "entre mesures" et "entre essais". Le résumé de ces analyses de variance est donné ci-dessous.

	Carrés moyens & degrés de liberté (entre parenthèses)				
	A	B	C	D	E
Essais sur "témoins"					
mesures	29,7(I6)	I55,5(I5)	80,-(I5)	I67,9(I5)	I2,6(I5)
essais	461,6(I5)	224,6(I4)	395,8(I4)	I80,3(I4)	404,3(I4)
Total	238,7(3I)	I88,9(29)	232,5(29)	I73,9(29)	20I,7(29)
Essais sur "gelés"					
mesures	206,3(I6)	9I.2(I5)	I47,5(I5)	357,7(I5)	II0,5(I5)
essais	344,9(I5)	603,5(I4)	3204,-(I4)	2062,8(I4)	I80I,7(I4)
Total	273,4(3I)	338,5(29)	I623,I(29)	II70,5(29)	926,3(29

Les I2 analyses de variance donnent des éléments de dispersion très différents. Même si l'on considère uniquement les carrés moyens entre mesures -qui correspondent à des conditions expérimentales aussi bien définies que possible- on constate que les 6 valeurs du groupe "témoins" constituent un ensemble hétérogène; il en est de même dans le groupe des "gelés" et à fortiori pour l'ensemble des I2 carrés moyens.

Nous conclurons en disant que l'analyse statistique des résultats d'une expérience, aussi bien organisée soit-elle, doit être faite non pas mécaniquement, mais avec le maximum de précautions et de discernement. Chaque fois que cela est possible, il est utile de procéder à une étude critique des constituants de la variance résiduelle, comme on vient de le faire dans les trois exemples précédents. Si des éléments d'hétérogénéité importants apparaissent, il sera prudent de renoncer à l'analyse simultanée de tous les résultats et d'effectuer plusieurs analyses distinctes, en scindant l'expérience complète en plusieurs sous-expériences distinctes. En effet, -et nous ne pouvons mieux faire que de citer à nouveau les auteurs suisses de l'"Etude sur le rendement des scies":

"Le carré moyen (résiduel) est une quantité complexe pro-
"duite d'une part par l'erreur expérimentale -d'où la dési-
"gnation souvent employée de variance de l'erreur- et d'autre
"part par des facteurs secondaires, tels que les interactions
"et les conditions extérieures, par exemple facteurs dont
"l'effet ne peut pas toujours être relevé par l'expérience.
"Il peut arriver qu'un de ces derniers ait un effet considé-
"rable et conduise l'expérimentateur non averti à des résul-
"tats inexacts. Disons encore que le choix du plan de l'expé-
"rience dépend, dans une large mesure, du comportement de ces
"facteurs".

Les agronomes, lorsqu'ils comparent dans le milieu naturel des dispositifs en "blocs", en "carré latin", etc...- (dont l'origine, rappelons-le, est agronomique) plusieurs variétés, ou plusieurs formules d'engrais, savent bien que les conclusions de l'analyse statistique n'acquièrent un caractère vraiment généralisable que si elles se trouvent confirmées pendant plusieurs années ou sur plusieurs stations. Ne doit-on pas recommander à ceux qui font de la recherche dans le domaine industriel d'adopter, chaque fois que cela est possible, la même attitude, c'est-à-dire de répéter les expériences? Les répétitions permettent de mieux préciser les contours de la population de référence à laquelle les conclusions pourront valablement s'appliquer. Si l'on me demande de prendre quelques boules dans une urne, et d'en tirer des renseignements sur la composition de l'urne, je pourrai m'engager à le faire quel que soit le nombre de boules qui me sera imposé. Si l'on m'a bandé les yeux, et qu'on m'annonce ensuite que plusieurs urnes se trouvaient dans la pièce où j'ai opéré, je différerai mes conclusions tant que l'on ne m'aura pas autorisé à prélever dans chaque urne.

Simplicité et difficultés de la statistique... L'établissement d'un plan de contrôle (à la réception ou en cours de fabrication), l'organisation d'une expérience, sont choses

plus ou moins difficiles, mais toujours difficiles. L'éxécution des opérations est généralement simple si les consignes ont été données de façon très précise. L'interprétation peut se contenter d'une banale honnêté dans le cas des contrôles de réception; elle demande de l'intelligence dans le cas des contrôles en cours de fabrication; elle exige un gros effort de réflexion et un esprit critique très délié lorsqu'il s'agit d'expériences.

Dans une réunion où, seul statisticien, j'étais en butte aux réflexions malicieuses de ceux pour lesquels la statistique se définit encore comme une "forme évoluée du mensonge", je formulai mon opinion de la façon suivante: Tout ouvrage de statistique devrait être entouré d'une bande qui mentionnerait, non pas qu'il s'agit d'un "best-seller", mais "Statistique: à ne pas mettre entre toutes les mains", ou "Pour lecteurs avertis seulement".

Ce sera ma conclusion.

R. C. A. F. QUALITY CONTROL

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It is now almost twenty years since the first RCAF Inspector poked a wary nose into the de Havilland Aircraft Company's door. What thoughts he had at the time were not recorded; perhaps he was too nervous to think, since he surely had his hands full. What he had to do was quite clear, but how to do it was a different matter; the RCAF had never had an AID Inspector before. What has happened in the years between in itself would make an interesting story, but a more immediate point of interest is that, despite the lapse of time, the "what" of RCAF Quality Control has changed not one whit, only the "how" has.

The unchanged role of RCAF Quality Control is described officially as follows:-

"To safeguard the interests of the Department of National Defence in respect of contracts for the supply and repair of aircraft stores and equipment, and to interpret to the Contractor the Department's requirements covered by the contract and related specifications."

To fulfil its allotted role the RCAF Quality Control Organization, then known as the Aeronautical Inspection Directorate, first adopted a system of duplication of contractors' inspection at all the important stages of production, with particular emphasis on final inspection and acceptance. The "stage" inspection system was used throughout the war and the immediate post-war period with good success, though it was recognized that it was wasteful of manpower and left room for improvement. However though room for improvement existed, time did not and it was not until the quiet period between the late hot and the present far from hot wars that the time was found.

The problem was far from simple, especially after the aircraft industry began to boom again; the RCAF had to achieve with a relative handful of men what it had in former days with many times that number. To do it a new philosophy had to be adopted and with it all the consequent changes. It was not an overnight achievement, indeed years have elapsed and still more years will pass before the ultimate is reached, if it ever is, but out of it all a pattern has emerged that bears summing up.

To define RCAF Quality Control exactly is difficult, it is a composite of so many related functions. The task has remained unchanged but methods have not. Academically speaking RCAF Quality Control is not complete within itself. It relies upon a close relationship with the Contractor's inspection or quality control organization; it does not supplant but rather supplements or augments. So that to describe RCAF Quality Control adequately requires at least cursory examination of the contractors share of the responsibilities.

The present RCAF system of Quality Control is often referred to as the "surveillance" system; the term should be familiar since it is also used by the United States Air Force, upon whose experience we have drawn in recent times. However, ours is surveillance with a difference since it was adapted to the already existing "Approved Firms" system. The problem of fitting these systems together into a cohesive

whole was simplified by the acceptance of Juran's definition of the Quality Function modified slightly to suit our needs. Juran describes the Quality Function as consisting of three elements - INSPECTION - QUALITY CONTROL and QUALITY ASSURANCE. The responsibilities which fall quite naturally to each of these elements are shown in the table below.

INSPECTION (Acceptance)	QUALITY CONTROL (Prevention)	QUALITY ASSURANCE (Assurance)
Receiving Inspection	Economic Studies	Field Complaints
Process Inspection	Process Capability Studies	Accuracy of Inspectors
Finished Parts Inspection	Design of Experiments	Check Inspection
Gauge Maintenance	Design of Sampling Plans	"Process" Inspection
Test Equipment Maintenance	Analysis of Data	Quality Audit
Salvage - MRB	Statistical Methods	
Day to day troubles	Training in Quality Control	

The Inspection or Acceptance element needs no description; it is safe to say that virtually every contractor in Canada has some form of inspection department, certainly every contractor dealing with the RCAF must have as a prerequisite to R. C. A. F. approval.

The second element of Quality Control, or Prevention, has not reached nearly the same stage of development as that of Acceptance. However the advantages of an organization dealing exclusively with Prevention have been and continually are being demonstrated and it would seem to be largely a matter of time before all but the smallest of contractors will introduce this element of Quality Control of their own volition.

The third element of Quality Assurance was completely unknown in Canada and to most would seem to offer little but another burden, but to the RCAF seeking a way to reduce its manpower overhead without sacrificing the ultimate aim of assuring quality products at economic costs, the idea of Assurance seemed like the answer. It is on the Assurance element of the Quality Function that the RCAF has concentrated its efforts over the past few years.

Accepting the given definition of the Quality Function it becomes a fairly simple matter to separate those responsibilities which quite obviously are the contractors from those which the RCAF must assume to accomplish its task. Broadly the contractor is held responsible for all the "working" aspects of the Quality Function, whilst the RCAF conducts the Assurance phase. Quite naturally there is some overlapping and duplication of work, for example the RCAF Inspector is the most immediate contact between the contractor and the customer and in that capacity may be called upon to interpret RCAF requirements; he is also the final judge of quality since he must accept the end product on behalf of the RCAF. These activities are not, however, completely incompatible with Assurance, in fact in many ways they might be considered complementary to it.

The contractors' responsibilities with respect to the Quality Function are defined in RCAF specification PROC 101-1 Quality Control of Aircraft and Associated Equipment. This specification requires that the RCAF Approved Contractor provide a Quality Control system which will

satisfy all the requirements of the Inspection element and those features of the Prevention element which are of most value. The RCAF does not require any of the features of the Assurance element from the contractor, but assumes them as its own responsibility. In fulfilling this responsibility the RCAF first serves its own ends but incidentally it also provides to the contractor the third element of an almost ideal Quality Control organization.

Fig. 1 shows how RCAF Quality Control is organized to meet its responsibilities.

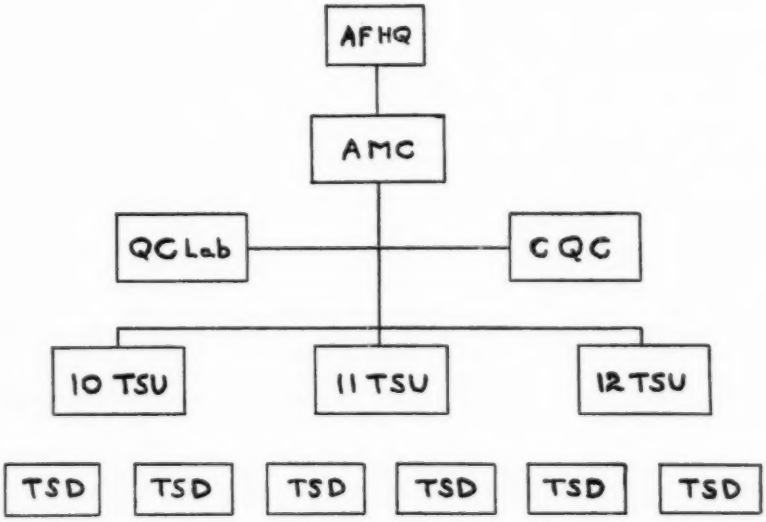


FIG. I - RCAF QUALITY CONTROL ORGANIZATION

Since basic policy is firmly established there is no staff at Air Force Headquarters dealing solely with the problems of quality control, though of course certain functions, such as the arranging of reciprocal inspection agreements with other countries are carried out by them.

Air Materiel Command is the body responsible to AFHQ for the quality control function; it has in its internal organization a staff known as the Chief of Quality Control which develops the plans and methods of quality control, conducts independent surveys, approves contractors and generally co-ordinates the work of the Technical Services Units with respect to quality control.

The Quality Control Laboratory provides a service to AMC and the Technical Services Units. One of its principal tasks is the training of RCAF Inspectors in both the basic fundamentals of inspection and the underlying philosophy of quality control. Other tasks include approval of operators and equipment for special processes such as X-ray, crack detection, welding etc., and more recently it has become the co-ordinating agency for the RCAF qualification testing programme.

The three Technical Services Units in the field concerned amongst other matters with quality control are located respectively in Calgary, Toronto and Montreal with each being responsible for the contractors in its designated area. Each of the TSUs varies in detailed organization but all follow the same basic pattern. Each has a number of detachments located usually with the principal contractors in the area and responsible for the supervision of those contractors. It is at the detachment level that the Assurance function is accomplished.

The responsibilities implicit in the assurance element of the Quality Function require measurements of the effect of field complaints and accuracy of inspectors, on quality, measurements of product quality by check inspection and an estimation of the efficacy of the contractors quality control system by process inspection. Correlation of the data obtained from these sources results in a relatively complete quality audit.

All the data required for the quality audit is available from one source or another, but due to the difficulties associated with assessing accurately their relative importance, particularly with respect to field complaints and the accuracy of inspectors, full use cannot be made of each. However since the data is available each aspect is considered in the light of its relative importance.

Field complaints relative to quality control are represented primarily by Unsatisfactory Condition Reports referred back to the contractor by AMC and Unscheduled Removal Tags attached to equipment returned for repair. Complaints of this sort are investigated quite exhaustively by both the contractor and the TSD and the results of investigation are collected and correlated by AMC. In the main, however, such complaints are far from a true index of quality since they lag too far behind actual production and are usually more indicative of failure in the matter of quality of design than in quality of conformance. Still they can be useful indicators of trouble areas and, to a limited extent of quality trends.

The accuracy of the contractors inspectors certainly has a direct bearing on the ultimate quality of his product and to some extent the data to assess it is obtained during the course of check inspection. Unfortunately no method has been devised of measuring this accuracy with any degree of exactness without most extensive re-inspection and even so the results would be open to the gravest of doubts when attempting to apply them to complex structures such as aircraft. So it would seem that measurement of the accuracy of inspectors is likely to remain an unsolved problem, unless some simpler yardstick involving relative assessments only is adopted.

Check inspection or re-inspection of the product is a more fertile field for the RCAF Inspector and produces important data for the Audit. Check inspection is of course nothing more than duplication of the contractors inspection; it is stage inspection applied with discretion. It is planned with two objectives in view; first it duplicates those inspection stages where safety is the primary consideration, for example flying controls, functional operation of systems etc; secondly it is carried out in sufficient detail to provide data on the outgoing quality of the product. Much more work remains to be done in this field, notably in standardizing the methods of collecting and recording data; many refinements may be added too, for example application of sampling

techniques,particularly in the inspection of single complex items, statistical analysis of data, classification of defects and so on. However, even lacking refinement the advantages of re-inspection to both the RCAF and the contractor are clear.

Process inspection, a term used by the RCAF to distinguish it from actual inspection of the product, is the study of those processes of manufacture and methods of control which contribute directly or indirectly to the ultimate quality of the end product. Such "Processes" range from the purely administrative problem such as distributing and amending drawings and other technical data, to the more technical problem such as control of tools and gauges. By assuming each process to be possessed of a certain number of characteristics and by studying a sample of these characteristics an estimate of the degree of control over the process as a whole may be arrived at. Similarly by study of an appropriate sample of the processes an estimate of the degree of control within the whole facility may also be achieved. Once again no absolute measure of efficiency is obtained but comparative results are and certainly any weakness in the system are quickly brought to light.

The sum of the work carried out in the Assurance element adds up to a quality audit. As in the commercial audit an inquiry is made not only into the accuracy of the system but also into its adequacy, but in contrast to the commercial audit the quality audit is a continuous rather than a discrete function. The results provided by the quality audit satisfy the RCAF requirement to safeguard the interests of the Department of National Defence and also provide to the contractor a continuous stream of information, which has been obtained independently and is comparatively free from prejudice, and on which improvement of his quality control system may be based.

QUALITY CONTROL APPLIED TO MANAGEMENT PROBLEMS

Dale L. Lobsinger
United Air Lines Inc.

Statistical Quality Control in the administrative areas of industry has a history as lengthy as it has in production processes. There is no comparison, however, in sheer volume of applications between the two phases of business. The latter far outstrips the former. This is not particularly surprising, inasmuch as logic would dictate that initial emphasis with such a tool be placed on improving quality of physical product -- the saleable element of most businesses. Nonetheless, results from use of the Statistical Quality Control methods in administrative areas have been significant.

A CLARIFICATION

At times interested persons are confused by the phrase "Administrative Applications of SQC." They mistakenly interpret this as a reference to administrating or conducting a general Quality Control program. Such is not the meaning intended. Instead, this phrase pertains to individual applications of Statistical Quality Control in those areas of business other than the technical aspects of production or research. Generally speaking it embraces the 'business of carrying on the business'. It includes analyses of such factors as inventory control, clerical activity, accounting and auditing, cost control, personnel evaluation and training, work sampling, customer reactions, sales forecasting, market research, work standards, and the like.

THE INSPECTION FUNCTION IN ADMINISTRATIVE AREAS

It seems to me that a few comments on this subject are in order. The need for scientific inspection in the administrative branches of business has been slow to receive recognition. Unlike production processes, where inspection generally has been considered an inseparable and indispensable function, the importance of setting up systematic reviews to assure quality of performance in administrative work too frequently has escaped the attention of management.

Currently, however, a growing concern is evident for the need of some method to keep management regularly apprised of quality in the administrative effort. All at once it seems administering a business is a sizable production in itself. Isn't it true, for example, that overtime work in many companies is a large and repetitive aspect of the business - year in and year out. It has its variables as well as similarities -- forming therewith a measurement basis of average and range. Then, too, most companies daily have a heavy expenditure of supervisory effort, quality of which is of constant concern to management. Generally, a certain variability is recognized here, but just to what degree and how costly is little known. Absenteeism among workers is another factor characteristic of most industries; but in how many instances can individual companies judge whether or not the extent is excessive. Everywhere, too, there seems to be a variety of complex service processes for which a reliable measurement technique is lacking to judge quality of performance.

These areas and others such as cost control, clerical activity,

inventory control, etc., are showing an increasing need for an effective audit or inspection method to aid management with clearer perspectives of what is happening from one period to the next.

SOME CASES IN POINT

Some time back I wrote about a few of the earlier SQC successes enjoyed by United Air Lines. All of these were clearly in the area of management problems. One of the first was associated with waste in food provided on airplanes (1). This involved a cost of about $200,000 annually — a figure sufficiently large to be of definite interest to the executive level. A study of the condition through $\bar{X}$ and R control charts revealed new and helpful information that made possible an 80 percent reduction in the waste.

In 1949, because of the effect on revenue, errors in our reservation service compelled the serious concern of our top management. It was obvious then, as it is now, that defective reservations could significantly influence the decision of a customer to continue or discontinue his patronage of our air line. The condition was analyzed with the help of NP control charts with the result that errors were reduced substantially, thus insuring for us a higher quality of reservation product with which to attract and hold the customer (2).

By now, of course, industry has quite an amount of literature to show that SQC methods are making a broad and important contribution in solving management problems. Especially impressive are the works of such men as Dr. Carl A. Noble, Guy G. Parkin, Charles A. Bicking, and Dr. W. Edwards Deming. Dr. Noble has effectively handled cost control in a paper industry (3). Mr. Parkin's application of SQC to Sales Forecasting and Control of Inventories has been very successful (4). Dr. Deming's work covers a wide field, with one of his earliest and most significant experiences being in the U. S. Bureau of Census (5). Then the "Ten Case Studies In Quality Control of Business Administration" by Mr. Bicking are, of course, classic in the field (6).

Interestingly enough, as illustrated through the above, essentially the same SQC techniques are used for both administrative and production line applications.

SQC TO AID AND EVALUATE SUPERVISION

During the past decade a sort of will-of-the-wisp goal of many progressive managements has been that of establishing a reliable method for evaluating supervisory output. Coupled with this has been a growing recognition that some form of technical aid is required to assist the supervisor himself in the face of mounting complexities in his responsibilities. This has made for a two-headed problem in a vital link of the management chain; and in this area Quality Control Engineers are spending more and more time.

Testing the methods of SQC for application to supervisory problems goes back a number of years. Messrs. Parkin and Bicking, as mentioned in references (4) and (6) above, did much for the cause. As a matter of truth, it was from leads of men just such as these that I have been encouraged to explore the area myself.

FIGURE I

At the present time we have a project going in the Transportation Services Administration of United Air Lines which we feel makes profitable use of SQC techniques applied to supervision. We call it: -

QUALITY ASSURANCE IN SUPERVISION

The word 'assurance' when applied to quality in the performance of men seems to be more palatable than the word 'control'; at least we find it so. Psychologically, 'assurance' seems to connote a cooperative venture, whereas, 'control' suggests a condition imposed.

In the balance of this paper I should like to describe an application in our airport ramp operation. Though this will tend to concentrate on a single area in management, actually it touches on many. I say this to reconcile the suggestion given in the title of the paper to the effect that a number of problems will be treated.

Ramp operations form a strategically important aspect of air transportation. It is the area where a good part of the success for schedule dependability rests. In United Air Lines, top supervision here generally bears the title of Chiefs of Station Ground Services. For brevity hereinafter these persons will be referred to simply as Chief.

To make the presentation more realistic, I would ask the reader to place himself in the position of the Chief as the latter faces his day-to-day work. He is one of five to provide 24 hour coverage — 365 days per year over the ramp function.

In Figure I we have a picture that suggests pretty well the scope of the Chief's work on the ramp. Here he is charged with overall responsibility for the many jobs which must be done. He may delegate authority to handle some of the work, but not the responsibility for it. This remains entirely with him -- and he in the final analysis is held answerable for both the good and bad performance.

But take a close look here! Can he as an individual possibly know about all the things which are done -- those which are correct, and those which fail to conform with operating procedures? Not one, but seven airplanes such as the one pictured to be serviced simultaneously — 75 to 100 working personnel assigned to the area, plus approximately 300 passengers moving about. All of the cargo, fuel, dining service, and cleaning work to be accomplished; the variety of automotive equipment being positioned here and there; these and many other factors all to be handled on a very rigid time schedule! Let's ask the question again. Can the Chief say confidently that he knows all that is occurring here? The answer, of course, must be 'no'.

But he is still responsible! This is his job to know what is happening.

Well, the truth is that the Ramp Operation is one of several activities which in recent years have grown in volume and complexity to such a degree as to require some form of analysis technique to assist supervision in satisfactorily meeting the needs of the job. And this is no reflection on the supervisor. No, it merely recognizes a basic change in job scope (something characteristic of most expanding industries), and to aid in answering the increased responsibilities our Quality

Assurance program was designed.

As employed in an area such as Ramp Operations, use is made of work sampling methods as contrasted to attempting a comprehensive understanding of total work. This simply means that the detail of the operation is studied a little at a time -- on a random basis -- so that over a certain period the bits of data may be assembled to cover all of the work and ultimately provide a picture of the whole. In this instance, the airplane itself is the unit of measure, or the sample employed.

In brief, periodically the Chief, through the 24 hour period, inspects all service factors on the ramp which pertain to a particular flight -- noting any and all violations of operating procedures or those conditions which fail to meet company quality standards. In truth, he is taking time out to judge performance strictly in terms of quality, making a record of all defects that come to his attention.

Note in this connection that he is adding nothing to his normal duties. He has always been responsible for the quality of which we speak. The simple difference in this program is that he changes methods in one aspect of his supervision. During these inspections he is going to make a record of weaknesses detected, so as to build for himself and the station a factual picture of what the real problems are.

Suppose we go along on a theoretic inspection. First, though, a little background is needed.

In broad terms, management interests in this area center around such factors as Accident Prevention, Compliance with Procedures, Housekeeping or Appearance, and the Passenger Handling Activities. These will form a frame of reference in the mind of the Chief as he approaches the ramp for inspection.

He starts the check by observing the guidance of the aircraft into the gate position. Certain inadequacies are noted here, namely, that the mechanic doing the guiding is not using the prescribed guide paddles. Even the direction the man gives with his arms is far from positive, and is such that conceivably it could be misunderstood by the pilot for whom it is intended. This not only makes for poor appearance, but it also fails to give the pilot the protection he needs. This parking of airplanes is more than a one man job.

The Chief's attention then moves to the start of fueling operation, a work of critical importance safetywise. The truck is positioned slowly and carefully. The grounding is accomplished properly, and the fuelers themselves observe all precautionary measures to insure a safe job. This part of the service is performed well -- which brings us to an observation concerning an interesting aspect of this particular sampling technique. The GOOD performance is accepted as a normal state of affairs, and as such is not noted for the record. It is only the defective work, or violations of operating procedures, that will draw the attention of the Chief. From the latter he will learn of the problem areas, and on the basis of added knowledge, guidance will be provided for improving performance.

But suppose we continue with the Chief. He heads for the other side of the plane and seems to have an interest in the handling of cargo. On the way, though, he stops and looks at the nose wheel. The

chock intended for securing this wheel is resting about 15 inches away, meaning that it serves no purpose. A note is made, of course, since the condition involves a safety factor. Perhaps this particular thing does not happen often, but the Chief is going to be sure. He will record the incident each time he sees it, and over a period of time find out for sure about whether or not it is a problem.

The inspections, incidentally, are made unobtrusively. It is as though the Chief is making his usual turn around the ramp area. But, there is a difference! Remember, he is making a record of what he sees to build a factual basis on which to plan future action. A simple difference, but an important one. To continue, however, the Chief now checks the position of the cargo belt loader and finds that it is rubbing against the plane. This allows for abrasive and damaging action during loading and unloading work.

Next, a man is seen to be jumping from a cargo belly pit of the plane instead of using a stand as procedures require. This is a personal safety item. Then a tractor is found to be unattended while the engine is running. These items the Chief is listing as violations of operating practices.

What else though? In watching the cargo being worked, it is found that faulty practices are making for double handling and requiring more time than actually necessary. Here and throughout the inspection the Chief is constantly posing such questions to himself as: "Is the appearance and action of personnel up to United Air Lines' standard?" "Is equipment all being handled safely and efficiently?"

The cleaning crew comes from the cabin of the airplane. Shall we check to see how well their work was done? Inside of the cabin things appear quite orderly and clean -- at least, generally. We want to be sure, however, that from a passenger service viewpoint, some of the smaller but more important details of cleaning have not been overlooked. The lavatories, for example. One sparkles. In the other, though, the Chief finds that someone did not complete the job. The sink is messy and there is debris on the floor. Another defect!

About time now for the flight to be announced for departure, and off we go to observe the closing out phase of trip handling. A good smile is on the face of the agent as he takes tickets and thanks our customers for their patronage. Timing seems to be right as the loading is completed, and the rolling stock is removed from the area. Finally, a careful and business-like dispatch of the trip, and this inspection comes to a close. Thirty minutes of detailed observation have provided a cross-section of quality in ramp performance

It is important to explain at this point that we accept the fact that some phases of the handling have escaped the Chief's attention. This should not be surprising, though, for the detail is almost unlimited. That which was missed, however, particularly if it is a repetitive form of defect, will surely appear in later inspections either by this or another Chief. Of prime concern to us, however, is that the observations were made as carefully as possible, and a record of same established in black and white.

Now, what has been seen. Back in the Chief's office suppose we

review the findings. First, there was the inadequate positioning of the aircraft itself — Figure 2. This is noted under the heading of Accident Prevention. Then in order we noted something about the chocks, the belt loader, the tractor running unattended, the man jumping from the pit, the double handling of cargo, and the dirty lavatory. See how each entry of a defect is placed under the major category to which it pertains. These, you remember, formed the background approach as the Chief started to take this sample of performance.

FIGURE 2

QUALITY ASSURANCE— Ramp Supervision

DATA SHEET

ACCIDENT PREVENTION	CHECK EACH DEFECT
Ramp man failed to use paddles on positioning plane	✓
Chocks too far from nose wheel	✓
Belt loader rubbing skin of plane	✓
SUB TTL	3

PROCEDURES	
Tractor engines running when not attended	✓
Ramp man jumped from belly pit - no stand used	✓
Dble handling of cargo account insufficient carts used	✓
SUB TTL	3

HOUSEKEEPING	
Right lavatory left messy by cleaning crew	✓
SUB TTL	1

PASSENGER HDLG ACT	
SUB TTL	0
TOTAL	7

FLIGHT/DATE 735/ Feb 20 SIGNATURE S. Parker

But now that we have this record of 7 defective conditions, does it mean that each of these items is a problem at the station. Not necessarily. Some may be -- others will not. Recall that in this method of studying performance, there will be more checks made of other flights, at other times, and by other Chiefs. How, then, do we determine just what our problems are? The answer is really quite simple. The findings of each inspection are tallied to a summary sheet under the proper classification, and here you see the value of the program taking shape. Figure 3.

FIGURE 3

Quality Assurance

RAMP SUPERVISION

TALLY AND SUMMARY

ACCIDENT PREVENTION

1	FUELING - GAS	|||||	6
2	GUIDANCE - AIRPLANE		3
3	" - OIL TRUCK	||||	4
4	" - PASSENGER STAND	|||||	6
5	" - BELT LOADER	||||	7
6	RECKLESS DRIVING	||||	11
7	UNSAFE ACTION OF PERSONNEL		5
8	DANGEROUS LIQUIDS ON WORKING SURFACE		6
9	MISCELLANEOUS	|||||	5
			11

PROCEDURES

1	VIOLATION OF FUELING PROCEDURE		4
2	ROUGH HANDLING OF CARGO	|||||	6
3	CARGO PROCEDURES VIOLATED	|||||	6
4	CABIN CLEANING PROCEDURES WRONG	|||||	6
5	ROUGH HANDLING OF FOOD EQUIP	||||	7
			73

APPEARANCE

	EQUIPMENT UNCLEAN		7
2	PERSONNEL APPEARANCE OR ACTION NOT GOOD	|||||	8
3	EXTERIOR OF PLANE UNCLEAN	||||	9
4	CABIN EQUIPMENT IN MESSY ARRANGEMENT	||||	11
			45

PASSENGER HANDLING

	HOLDING AT GATE TOO LONG AFTER ANNOUNCEMENT		3
2	FAILURE TO KEEP PASSENGERS ACCURATELY ADVISED		4
3	PASSENGERS WANDERING UNATTENDED ON RAMP		3
4	MISCELLANEOUS	|||||	22
			32

Someplace here each of the incidents recorded by our Chief have been tallied. Study this form a bit. It isn't difficult to see that following a number of inspections the heavy tallying begins to show you where trouble exists. Actually, problems as far as management finding them is concerned, are reduced to simple numbers. (The circled totals at right). By simple arithmetic guidance is provided for the improvement needed, and this generally takes the form of increased supervision over the function. Clearly, this is an important factual aid.

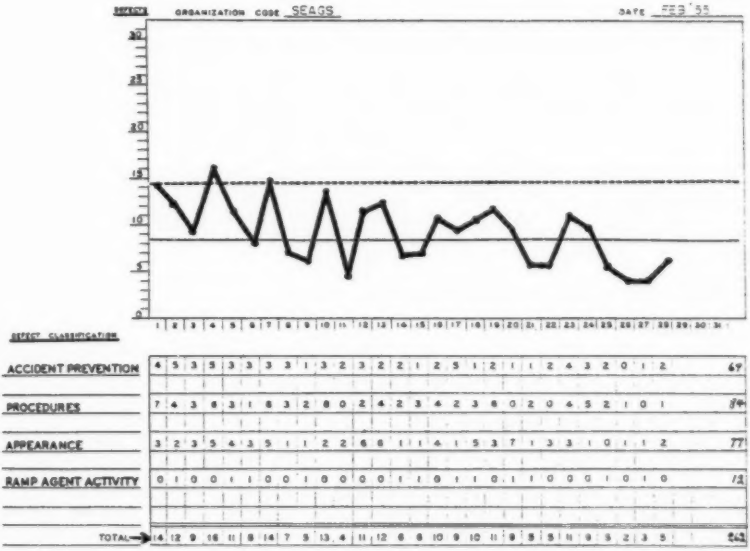
It should be readily apparent how well the technique fits into our training program. Figure 3 shows a need for improvement in the general placement of equipment around the airplane. Accordingly, those employees concerned are gathered in a training session to review requirements, and to be reminded of the extreme importance of carrying out the work properly. Clearcut data shows were their efforts should be concentrated!

The control chart, of course, gives a ready day-by-day reference to serve the interest of the Manager of Station Ground Services, the Chief's supervisor. Figure 4. It shows the trend of general performance quality as well as broad indicators of the phase of operation giving the most trouble.

The final and most important phase of the program is that which studies supervision itself. It pictures the method in which each supervisor or Chief sees his responsibility through the inspection facility. Figure 5. This has benefits for both the manager of the function and the various levels of supervision. Primary interest here, of course, centers around an analysis of variation between supervisors, and the objective is that of developing a general uniformity.

FIGURE 4

QUALITY ASSURANCE- RAMP SUPERVISION



We are not suggesting that all managers and supervisors should be exactly alike. Far from it! That not only is an impossibility, but also is undesirable. It is helpful to know, however, when variations between an important management group (such as Chiefs in Ramp Service) are excessive. It will often mean that one or the other may have relaxed attention slightly on an important phase of work, and he should do something to round out and bring his supervisory efforts into better balance with others.

This chart helps greatly in such a purpose. See how one concentrates his findings of defects more in one area than another. Often this is done to the neglect of other responsibilities. In reading the chart you see the percent of total defects by broad classification as found between the inspecting Chiefs.

FIGURE 5

SUPERVISORY COMPARISON

SUPERVISOR	NO. OF INSPECTIONS	AV DEFECTS PER INSPECTION	% IN ACCIDENT PREVTN	% IN PROCEDURES	% IN APPEARANCE	% IN RAMP AGT ACTION
A —	16	1.87	16	26	46	12
B —	22	3.72	30	33	34	3
C —	20	2.10	40	35	19	5
D —	10	5.50	14	36	42	8
E —	24	3.50	29	33	33	5
STATION RECORD	92	2.80	27	33	34	6

CONCLUSION

Currently the Quality Assurance program for Supervision reaches into four major functions of United Air Lines' Transportation Services Administration. These are the Air Freight Activity, Dining Service, Mechanical Maintenance, and Ramp Operations. All are heavy volume and complex work areas which are rather taxing to supervision. It is our belief that the chart principle of Statistical Quality Control as described above and applied to analysis of these functions, has made a very worthy contribution to our management techniques.

As a close, I would repeat the thought that many businesses seem to be overlooking the complex nature of responsibilities assigned to supervisors and the associate need therein for providing this personnel with a method for better understanding and controlling trends related thereto. At the same time, I believe that supervision in general would welcome an objective method for evaluating their output. The degree of acceptance for them, of course, will depend heavily on the skill of introduction. SQC principles offer an attractive vehicle for accomplishing this.

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ELECTRONIC SYSTEMS FAILURE REPORTING METHODS

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I. INTRODUCTION

Vital to the success of any Reliability Program is an efficient system for reporting equipment failures. Any particular system developed, however, derives its detailed procedures from the organizational relationships influencing it. Therefore, rather than today presenting any particular concept of a feedback reporting system, let us review, in general, the composite or consensus of a number of different approaches which have been made to the feedback of failure data, with specific suggestions of general approach which have been found of value in deriving efficient failure data.

Before going into the subject of failure reporting, let us first look at the problem which has stimulated the development of the various failure reporting methods to be discussed.

Reliability Programs are actually an expression of the need for a systematic scientific approach to the control of Quality, generated by the increase in complexity of the articles being produced. As scientific and technical developments progress, the resultant operational equipment becomes more complex. This complexity degrades the reliability of the equipment as a function of the quantity and unreliability of the individual units which comprise the systems. I am sure we are all aware that in order for a complex system to perform with any degree of reliability, the details which comprise the system can fall short of 100% reliability by only an infinitesimal amount. These statements have been proven in actual use of complex equipment. Where normal manufacturing and test methods which had previously proven satisfactory were used, equipment performance fell far below that which could be considered reliable.

Two major results derive from the use of unreliable equipment. One, failure to perform a required function. This may be vital in some applications. And, two, extreme cost of maintenance. Recent studies for the military agencies have indicated that cost of maintenance of equipment far exceeds the cost of initial acquisition. These factors have influenced the development of reliability programs for the purpose of extending the performance of an item beyond that of satisfactory operation at time of delivery. Customer satisfaction in complex equipment, which is the ultimate goal, can only be obtained by high quality of design and high quality of conformance to design requirements. This requires a coordinated effort between Engineering and Quality Control, with the full participation of Manufacturing, Purchasing and the Field Service Agency.

Essential, of course, to a Reliability Program is some standard for the measure of reliability. But where do we actually start? Hypotheses must be derived and data collected to prove or disprove these conclusions. From an analysis of failure information, an approach to reliability may be evolved, including expression of standards and correlation of data for further analysis. We will present today a look at some of the methods which have been derived for reporting electronic systems failures, and some of the methods which have been used to evaluate these failures.

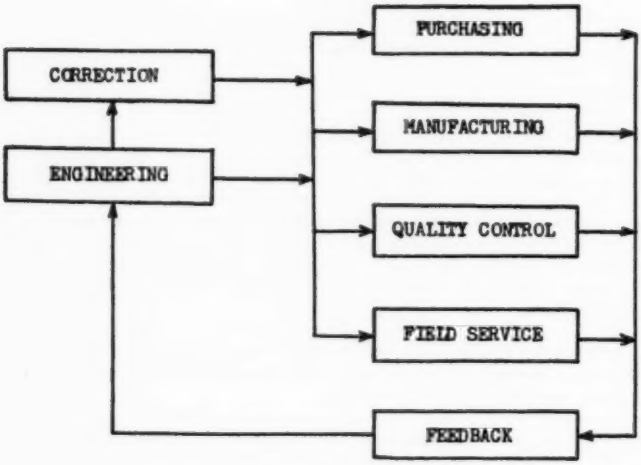


FIGURE I

II. FAILURE REPORTING

First and foremost in a failure reporting system is the ability to detect deficiency. Information which flows in a system of forms and procedures must first be efficiently derived and accurately recorded. It is here that the human element plays an important part in the feedback system. At whatever station or post that failure details are being recorded, the method for detecting the deficiency and recording it must be compatible with the level of ability of the person who will be required to perform this phase of the operation. There is a wide divergence in skills between laboratory engineers, factory technicians and service personnel or ultimate users. No matter how skillfully a failure feedback system is devised, the information is still dependent upon the human factor and this must be thoroughly studied prior to deciding the method for failure reporting and failure analysis.

The specific form, the information requested, and the details required must be established with specific regard to the individual who will be supplying the information. The confidence given to the analysis of information furnished can be established only with regard to the individual who will be supplying the information. As we examine some of the reporting systems which have been used for failure reporting, some of the incompatibility between systems will be due to the differences in reporting level or competence of the reporter.

In a large organization there are generally found many different types or levels of people upon whom the reporting of malfunctions must depend. For instance, there is the engineer who will probably channel

his thoughts along the design route; or, there may be the field service representative who has in mind the many environmental conditions, both handling and airborne, that may have a bearing upon the article; or, the manufacturing operator who is inclined, for the sake of brevity, to give a rather sketchy resume of the malfunction. The inspector, in the author's opinion, is inclined to give a less biased report as he generally has little reason, or desire, to protect or deprecate any particular group. There are, of course, many other groups of people whom we must consider.

III. REPORTING SYSTEMS

In order for a reporting system to be effective, the feedback loop must be closed, and it must also be completed as quickly as possible. However, it has been found that there must be a compromise between the speed of processing and the amount of information which is made available. A simple feedback loop, (Fig. I), would provide that deficiencies would be reported by the group with cognizance over the equipment. The report would stimulate engineering action resulting in corrective changes which would be applied to the equipment. This system would provide for correction of design deficiencies and may be accomplished with a simple form. We know, however, that engineering alone is not responsible for all defects which occur, nor can they take corrective action on all failures. This, therefore, requires that some agency perform some degree of screening failure reports to determine the area of responsibility, direct the report to the proper place, and follow-up to see that action is completed.

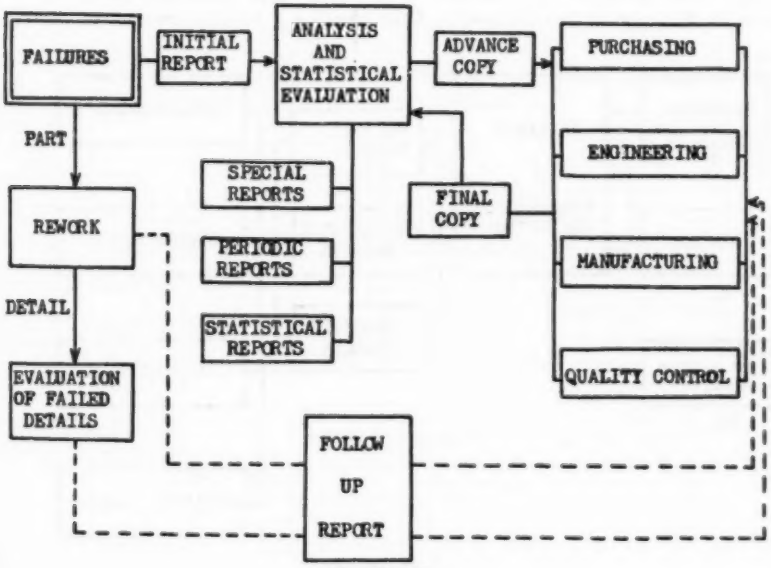


FIGURE II

Let us assume now that this is a development program, and follow-up and analysis on each failure is essential. (Fig. II.) In order to provide adequate information for analysis it may be necessary to delay reporting until the failure detail has been evaluated. This could result in intolerable delays in notification of important failures. To resolve the incompatibility between the need for, one, immediate information and, two, complete information, the report may be split into two parts. One, an immediate notification; and, two, a follow-up form which will provide failure details. The follow-up report may flow from the rework area, or the component evaluation area, or both. Various combinations of initiation and flow of both initial and follow-up reports may be made. In order to best utilize the information accumulated, an analytical group is provided to receive and distribute the initial report, maintain follow-up on the secondary report, and analyze results accomplished, publishing tabulations, statistical studies, and special reports. If the number of reports are few, and each failure is considered important, a marginal card punch sorting system may be used which permits extraction of the detailed failure information with little delay. However, this requires manual tabulation of reports. This system is used in one phase of North American Aviation reporting systems, by the Air Force for its Unsatisfactory Reports, and by other companies in special applications.

As production increases and large quantities of equipment are placed into operation, it becomes evident that this type of system is too cumbersome to handle the large volume of reports which will flow from various locations. Also, the emphasis must be shifted to analysis of failure rates, stressing frequency of failure rather than individual failures. The difference in approach permits a change in the feedback system. Less detailed information is necessary and immediate notification of failure is unimportant. This permits a simplification of flow

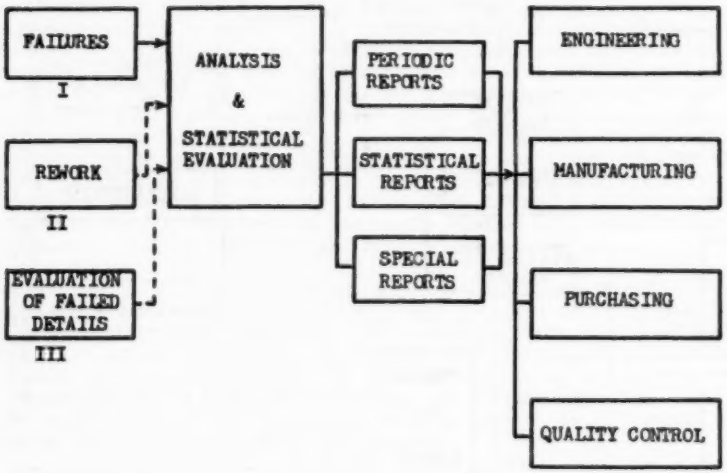


FIGURE III

and utilization of mechanical data processing systems. (Fig. III.) Three approaches are shown. The failure report may flow immediately to machine processing in which case, generally, failure levels and symptoms only would be reported. By delaying the report, pending analysis of the failure detail, a detail level report may be made. Or, carrying it one step farther, a "post-mortem" analysis of the detail may be included.

This, in essence, is the basis for reporting systems and numerous modifications and offshoots exist. For your further study, some additional examples of feedback system flow diagrams have been included, however, these will not be discussed at this time. These are, (Fig. IV), a system used in an electronics manufacturing plant, (Fig. V), which utilizes a coded checkbook size report form with a new form being initiated for each sequence in processing a particular item, and (Fig. VI), the dual flow system used by North American Aviation in the missile and electronics program. This is the complete system using two separate forms combining the development system and the production system into one comprehensive flow chart.

It can be seen that a variety of systems may be derived from the simple feedback loop depending upon purpose, compromise, extent of dispersion, quantity, organizational structure, the human element, and many other elements which influence the final pattern.

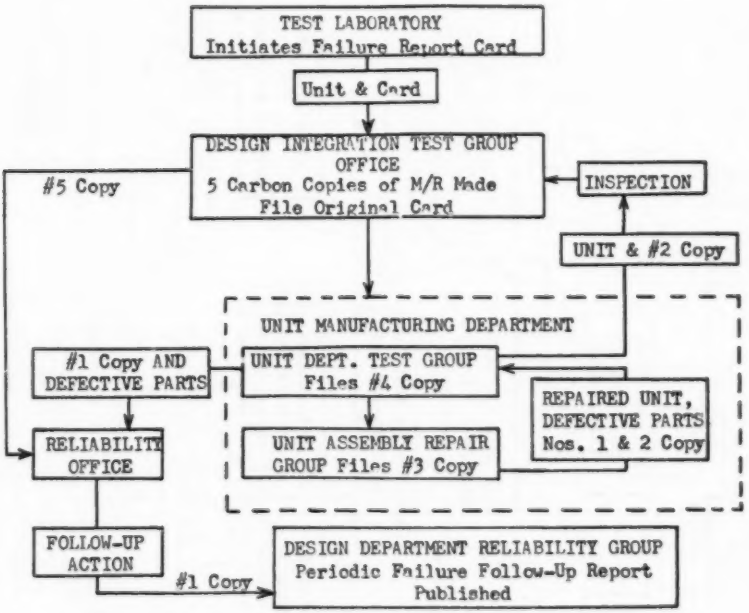


FIGURE IV

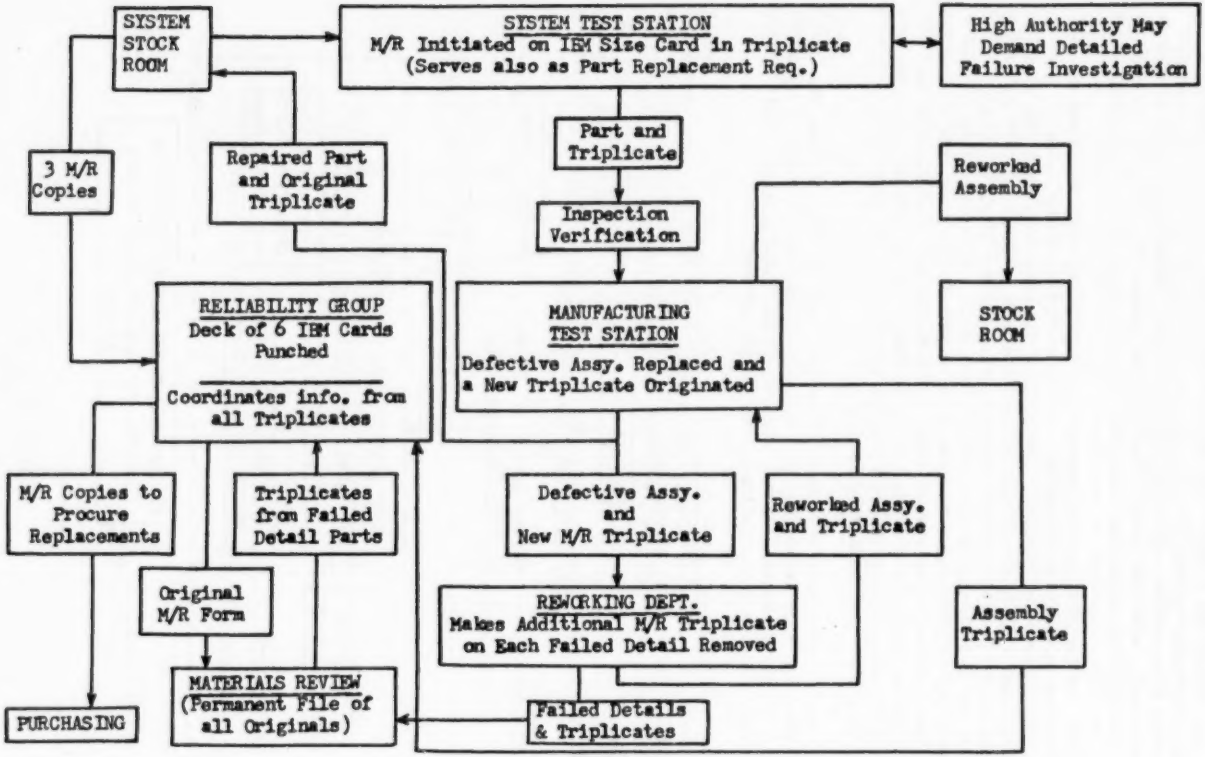

SYSTEM STOCK ROOM
SYSTEM TEST STATION
M/R Initiated on IBM Size Card in Triplicate
(Serves also as Part Replacement Req.)
High Authority May Demand Detailed Failure Investigation
Part and Triplicate
3 M/R Copies
Repaired Part and Original Triplicate
Inspection Verification
Reworked Assembly
RELIABILITY GROUP
Deck of 6 IBM Cards Punched
Coordinates info. from all Triplicates
MANUFACTURING TEST STATION
Defective Assy. Replaced and a New Triplicate Originated
STOCK ROOM
M/R Copies to Procure Replacements
Triplicates from Failed Detail Parts
Defective Assy. and New M/R Triplicate
Reworked Assy. and Triplicate
Original M/R Form
REWORKING DEPT.
Makes Additional M/R Triplicate on Each Failed Detail Removed
Assembly Triplicate
MATERIALS REVIEW
(Permanent File of all Originals)
PURCHASING
Failed Details & Triplicates

FIGURE V

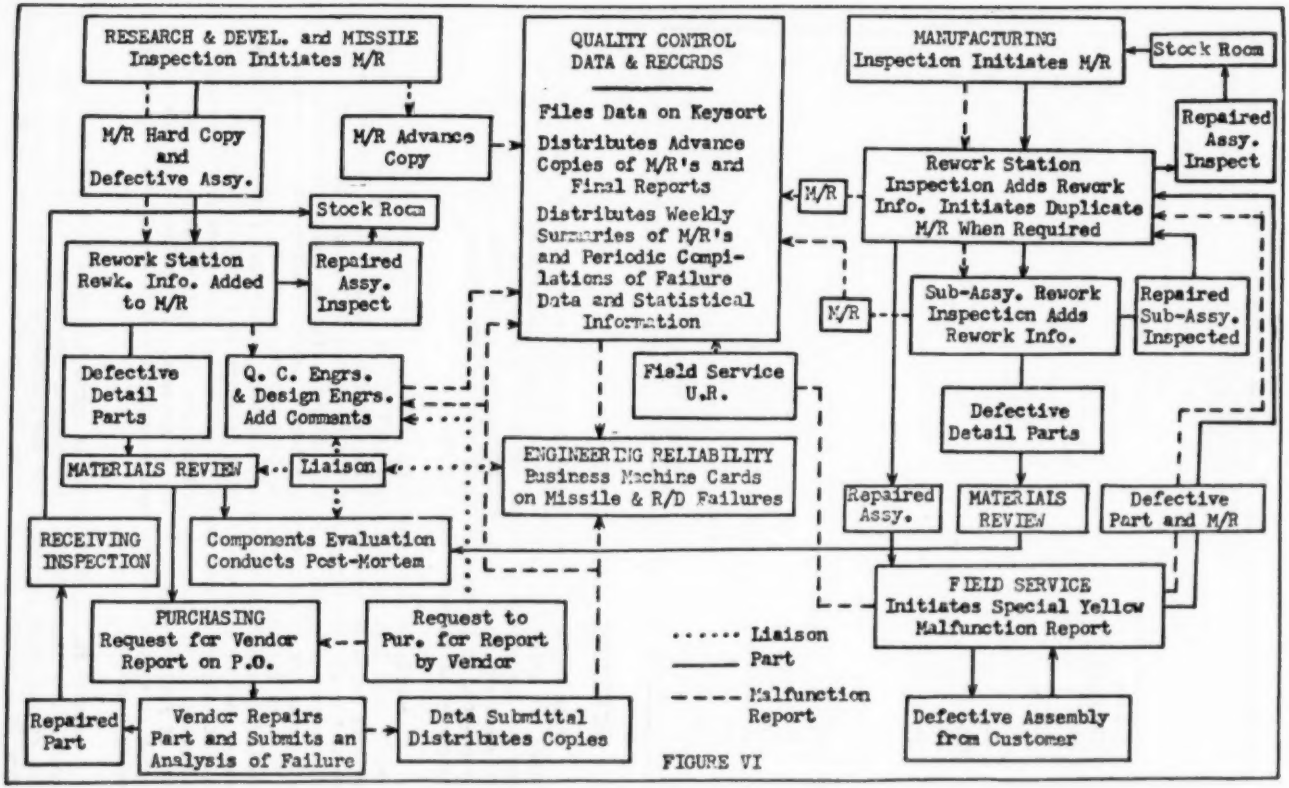
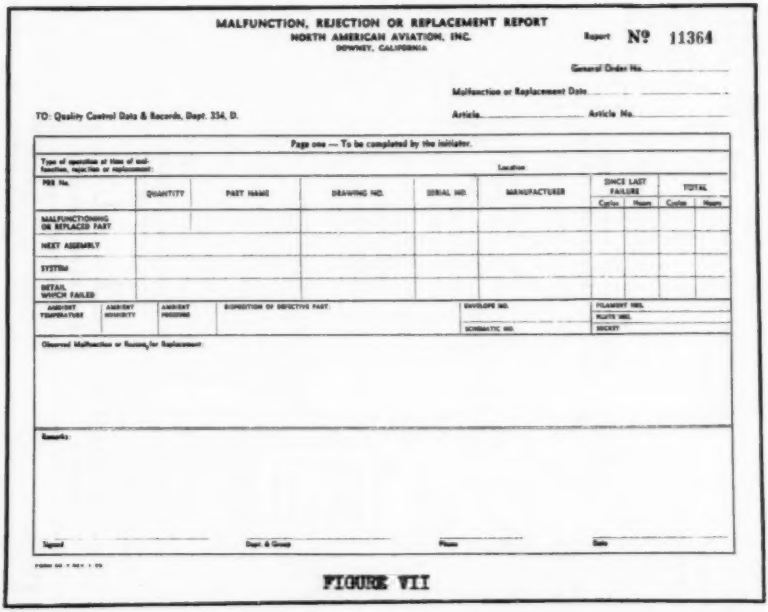

RESEARCH & DEVEL. and MISSILE Inspection Initiates M/R
M/R Hard Copy and Defective Assy.
M/R Advance Copy
QUALITY CONTROL DATA & RECORDS
Files Data on Keysort
Distributes Advance Copies of M/R's and Final Reports
Distributes Weekly Summaries of M/R's and Periodic Compilations of Failure Data and Statistical Information
MANUFACTURING Inspection Initiates M/R
Stock Room
Repaired Assy. Inspect
Stock Room
Rework Station Rewk. Info. Added to M/R
Repaired Assy. Inspect
M/R
Rework Station Inspection Adds Rework Info. Initiates Duplicate M/R When Required
M/R
Sub-Assy. Rework Inspection Adds Rework Info.
Repaired Sub-Assy. Inspected
Defective Detail Parts
Q. C. Engrs. & Design Engrs. Add Comments
Field Service U.R.
Defective Detail Parts
MATERIALS REVIEW
Liaison
ENGINEERING RELIABILITY Business Machine Cards on Missile & R/D Failures
Repaired Assy.
MATERIALS REVIEW
Defective Part and M/R
RECEIVING INSPECTION
Components Evaluation Conducts Post-Mortem
FIELD SERVICE Initiates Special Yellow Malfunction Report
PURCHASING Request for Vendor Report on P.O.
Request to Pur. for Report by Vendor
Liaison
Part
Malfunction Report
Repaired Part
Vendor Repairs Part and Submits an Analysis of Failure
Data Submittal Distributes Copies
Defective Assembly from Customer

FIGURE VI



MALFUNCTION, REJECTION OR REPLACEMENT REPORT
NORTH AMERICAN AVIATION, INC.
DOWNEY, CALIFORNIA

Report Nº 11364

General Order No.

Malfunction or Replacement Date

TO: Quality Control Data & Records, Dept. 334, D. Article Article No.

Page one — To be completed by the initiator.

Type of operation at time of malfunction, rejection or replacement: Location

P&S No.	QUANTITY	PART NAME	DRAWING NO.	SERIAL NO.	MANUFACTURER	SINCE LAST FAILURE: Cycles	SINCE LAST FAILURE: Hours	TOTAL: Cycles	TOTAL: Hours
MALFUNCTIONING OR REPLACED PART									
NEXT ASSEMBLY									
SYSTEM									
DETAIL WHICH FAILED									

AMBIENT TEMPERATURE	AMBIENT HUMIDITY	AMBIENT PRESSURE	DISPOSITION OF DEFECTIVE PART	ENVELOPE NO.	FILAMENT NO.
				SCHEMATIC NO.	PLATE NO.
					SOCKET

Observed Malfunction or Reason for Replacement:

Remarks:

Signed Dept. & Group Phone Date

FIGURE VII

IV. REPORT FORMS

It is folly to expect consistency in the reporting of malfunctions unless the reporting form has been specifically designed, not only to draw out the essential facts, but also to stimulate the thought of different reporters along a predetermined course from operation (environment), to observation (symptom), to action taken (rework), to assignment of cause (detail failure).

To emphasize the importance of using a carefully designed report form I would like to show you a part of the evolution of our malfunction feedback forms at North American Aviation. (Fig. VII.) Here you see one of the earlier forms used for reporting malfunction information on electronic components. In the left hand side we asked the reporter to categorize the failed part as either a malfunctioning part or as a detail which failed, and all the information necessary to positively identify the part is requested. However, later use of these reports revealed that we were experiencing failures on a certain item, but this did not tell us at what phase in production flow these failures were occurring. The inability to determine the environment of the part at time of failure made this form inadequate. The influence of interacting forces at system level is considerably different from those encountered during bench test.

Another factor that should be borne uppermost in the mind is the purposeful utilization and direction of personnel. To apportion the time of qualified personnel for the correction of someone else's mistakes is a serious problem facing the departmental chief. It becomes

increasingly important, therefore, to design a form which will direct the investigation to the right place with the minimum of time. Please notice the large areas for "Remarks". This does not stimulate the reporter's thoughts along the predetermined course considered essential to complete reporting, and required much editing and redirection of effort after erroneous conclusions were reached.

The next step, (Fig. VIII), was the design of a form embodying the principles we had now learned. This form specifically asks to what specification and paragraph was the part being operated at the time of failure. It also gives the relationship of the failed part to other assembled parts by requesting the reporter to indicate at what level the unit was being operated at time of failure, such as the system level, black box level, or package level. Our statistics, therefore, adopt a meaningful purpose. They tell us exactly when and where the part failed, thus saving considerable time and expense in pin pointing the trouble area.

Is the part <u>OK</u> without rework? This has been of great significance to us in flagging non-compatible specifications. Details of the rework must be requested on the form and not left to the reporter to list at his discretion in a space titled "Remarks".

A third step, (Fig. IX), towards the ideal form is this one. It incorporates many of the features of Figure VIII, but it is still more exacting in asking the reporter what was the condition of the failed detail. Instead of going off on a wild goose chase we want to <u>know</u> - are resistors breaking, or are they burning, or is the mechanic making cold solder joints, or a million other reasons for failure which should not be assumed.

MALFUNCTION & FOLLOW-UP REPORT
NORTH AMERICAN AVIATION, INC. DOWNEY, CALIFORNIA

PRR No._____ System No._____ Report No._____
(PLEASE TYPE OR PRINT)

WHILE:	THIS ITEM:			TO:	AT:
Operating ☐					Part Test ☐
Testing ☐	Name			Spec. No._____	Comp. Test ☐
Physically Inspecting ☐	Number	Ref. Sym. No.	Serial No.	Para. No._____	System ☐ Other ☐

The following malfunction was noted. (List specific deviations from Spec. requirements if applicable)

Signed_____ Dept. & Group_____ Date_____

INSP. State the rework and reason, then forward this form to the Quality Control Liaison Engineer.
DETAIL(S) WHICH FAILED

NAME	PART NO.	PRR	REF. SYM.	ENVELOPE

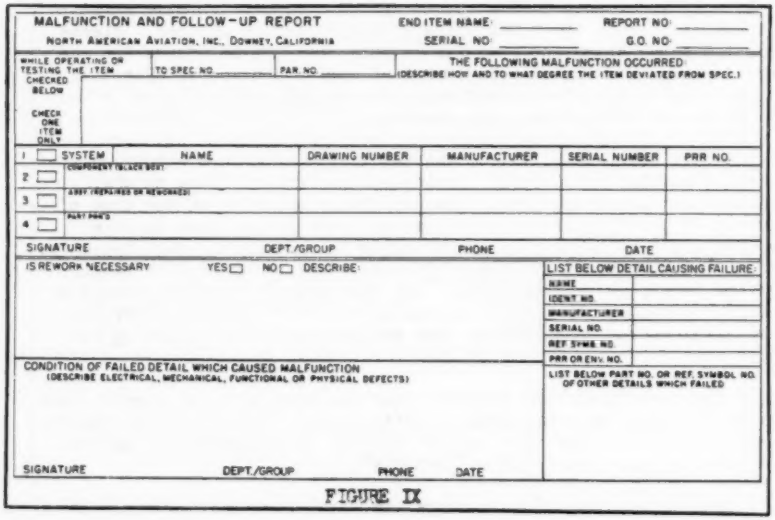
Did Part Pass Functional Test Before Rework?

	YES	NO
PART	☐	☐
COMPONENT	☐	☐

REWORK & REASON:

Signed_____ Dept. & Group_____ Date_____

FIGURE VIII



MALFUNCTION AND FOLLOW-UP REPORT

NORTH AMERICAN AVIATION, INC., DOWNEY, CALIFORNIA

END ITEM NAME: _____ REPORT NO: _____

SERIAL NO: _____ G.O. NO: _____

WHILE OPERATING OR TESTING THE ITEM CHECKED BELOW — TO SPEC NO. _____ PAR NO. _____

THE FOLLOWING MALFUNCTION OCCURRED: (DESCRIBE HOW AND TO WHAT DEGREE THE ITEM DEVIATED FROM SPEC.)

CHECK ONE ITEM ONLY

		NAME	DRAWING NUMBER	MANUFACTURER	SERIAL NUMBER	PRR NO.
1 ☐	SYSTEM					
2 ☐	COMPONENT (BLACK BOX)					
3 ☐	ASSY (REPAIRED OR REWORKED)					
4 ☐	PART PER'S					

SIGNATURE _____ DEPT./GROUP _____ PHONE _____ DATE _____

IS REWORK NECESSARY YES ☐ NO ☐ DESCRIBE:

LIST BELOW DETAIL CAUSING FAILURE:

NAME	
IDENT NO.	
MANUFACTURER	
SERIAL NO.	
REF SYMB NO.	
PRR OR ENV. NO.	

CONDITION OF FAILED DETAIL WHICH CAUSED MALFUNCTION (DESCRIBE ELECTRICAL, MECHANICAL, FUNCTIONAL OR PHYSICAL DEFECTS)

LIST BELOW PART NO. OR REF. SYMBOL NO. OF OTHER DETAILS WHICH FAILED

SIGNATURE _____ DEPT./GROUP _____ PHONE _____ DATE _____

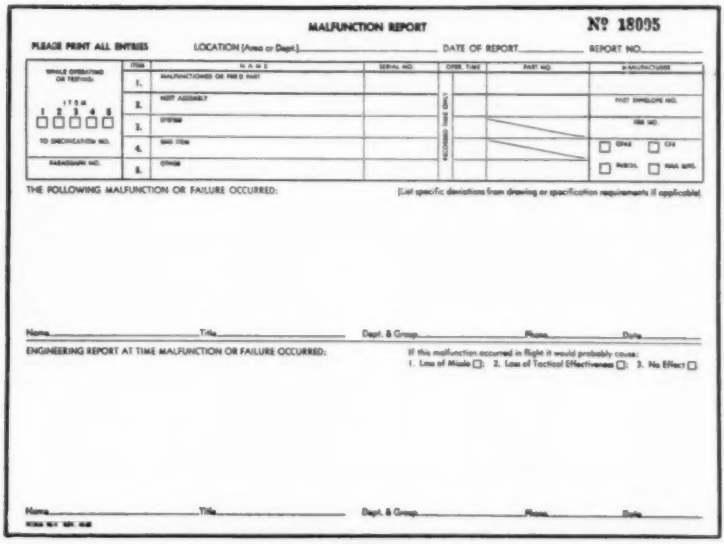
FIGURE IX

These changes which I have outlined are the evolution of our report forms for what we call production contracts.

In the production phase we are entitled to assume that potential catastrophes, if not entirely eliminated, are either under adequate control or reduced to an insignificant figure. We may then, with a clear conscience, think in terms of streamlining our reporting system. An approach toward streamlining the system is to take action only after an undesirable trend is evident. This approach, if followed properly, is not as complacent as one might be inclined to think. There should be a continuous effort to improve the worst offenders regardless of how good they may be. This concept becomes complacent only when a low standard of quality or design is expected or condoned.

For development work it is necessary to apply a slightly different philosophy; however, the forms, in concept, are similar. (Fig. X.) In this phase there generally is not a large homogeneous collection of parts and, therefore, it behooves us to review all malfunctions. This is accomplished by detaching a copy of the form for immediate notification and permitting a follow-up copy to flow with the part acquiring detailed information about the failure. Space is provided for entering the results of subsequent analysis by Quality Control, Engineering, or a separate group acting as a reliability agency. The functional chart, (Fig. XI), outlining the responsibilities of each stage in the progress of a defective part indicates the importance we attach to acquiring accurate information, performing a thorough analysis, and accomplishing corrective action on each significant malfunction. In the development phase we should regard every malfunction as a potential catastrophe until our facts and analyses suggest otherwise.

After an item has been delivered to a customer, reliance may be placed on feedback of customer complaints, or upon reports submitted by



MALFUNCTION REPORT

Nº 18095

PLEASE PRINT ALL ENTRIES

LOCATION (Area or Dept.)

DATE OF REPORT

REPORT NO.

ITEM	N A M E	SERIAL NO.	OPER. TIME	PART NO.	MANUFACTURER
1.	MALFUNCTIONED OR FAILED PART		RECORDED TIME ONLY		
2.	NEXT ASSEMBLY				PART SYMBOLIZE NO.
3.	SYSTEM				MFR NO.
4.	END ITEM				☐ GFAE ☐ CFA
5.	OTHER				☐ AGENCY ☐ MAN MFR.

WHILE OPERATING OR TESTING: 1 2 3 4 5

TO SPECIFICATION NO.

PARAGRAPH NO.

THE FOLLOWING MALFUNCTION OR FAILURE OCCURRED: (List specific deviations from drawing or specification requirements if applicable)

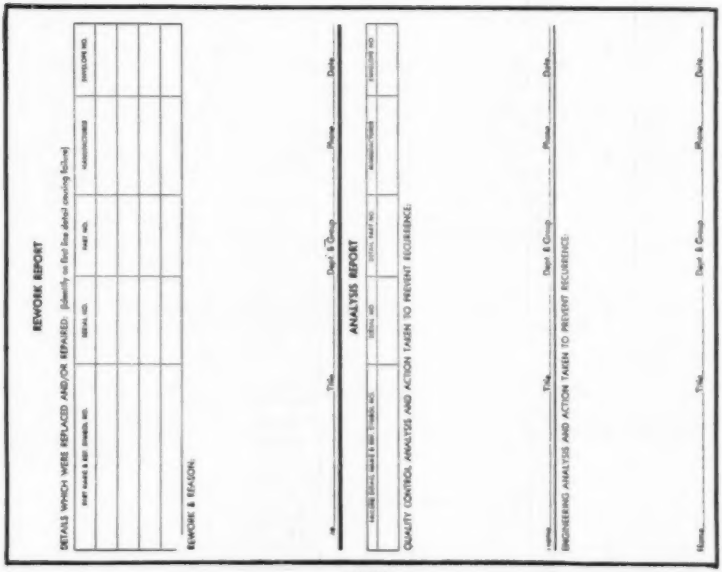
Name Title Dept. & Group Phone Date

ENGINEERING REPORT AT TIME MALFUNCTION OR FAILURE OCCURRED:

If this malfunction occurred in flight it would probably cause:
1. Loss of Missile ☐; 2. Loss of Tactical Effectiveness ☐; 3. No Effect ☐

Name Title Dept. & Group Phone Date

FRONT



REWORK REPORT

DETAILS WHICH WERE REPLACED AND/OR REPAIRED: (Identify on Bad Box dotted covering failure)

PART NAME & REF. SYMBOL NO.	SERIAL NO.	MFR. NO.	MANUFACTURER	SYMBOLIZE NO.

REWORK & REASON:

Title Dept & Group Phone Date

ANALYSIS REPORT

NEXTAGE BOARD NAME & REF. SYMBOL NO.	SERIAL NO.	SERIAL PART NO.	MANUFACTURER	SYMBOLIZE NO.

QUALITY CONTROL ANALYSIS AND ACTION TAKEN TO PREVENT RECURRENCE:

Title Dept & Group Phone Date

ENGINEERING ANALYSIS AND ACTION TAKEN TO PREVENT RECURRENCE:

Title Dept & Group Phone Date

BACK

FIGURE I

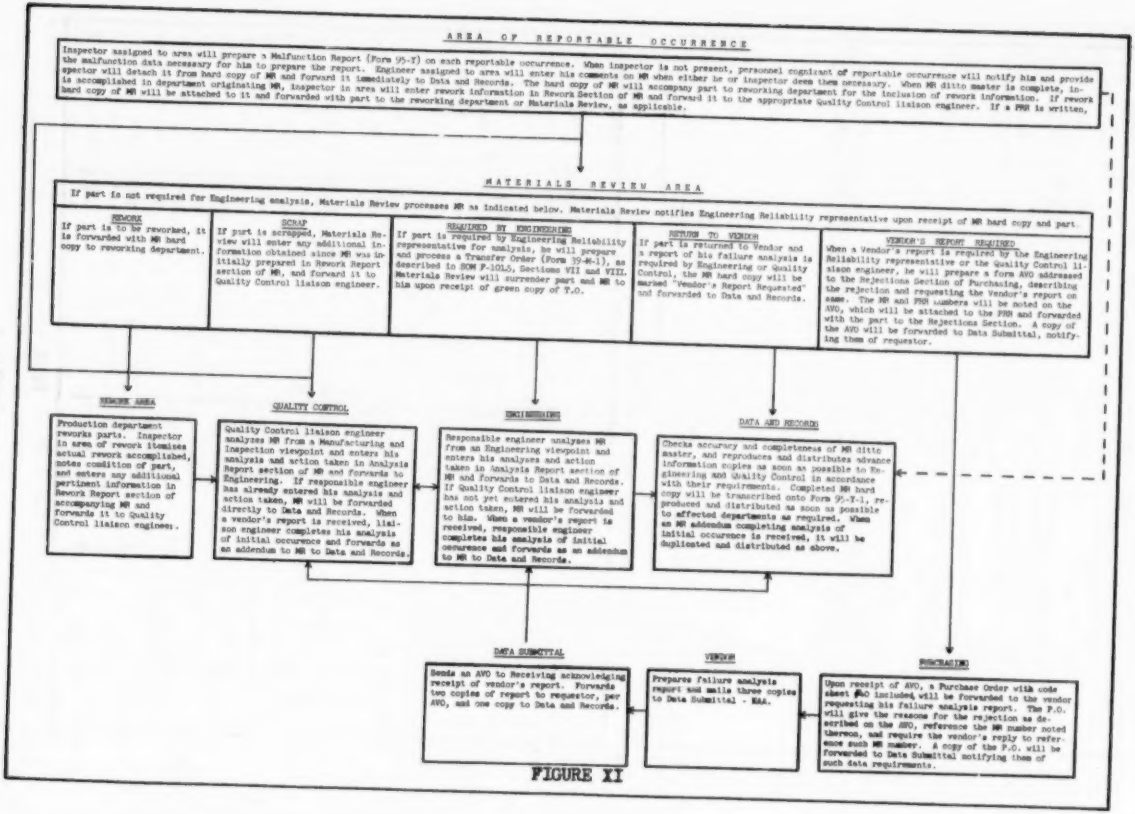
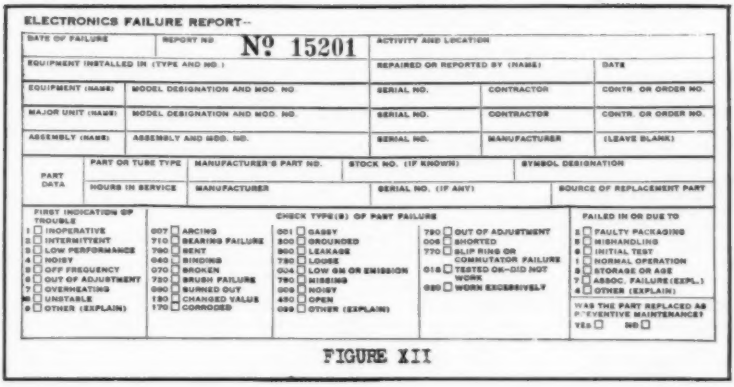

AREA OF REPORTABLE OCCURRENCE
Inspector assigned to area will prepare a Malfunction Report (Form 95-Y) on each reportable occurrence. When inspector is not present, personnel cognizant of reportable occurrence will notify him and provide the malfunction data necessary for him to prepare the report. Engineer assigned to area will enter his comments on MR when either he or inspector deems them necessary. When MR ditto master is complete, inspector will detach it from hard copy of MR and forward it immediately to Data and Records. The hard copy of MR will accompany part to reworking department for the inclusion of rework information. If rework is accomplished in department originating MR, inspector in area will enter rework information in Rework Section of MR and forward it to the appropriate Quality Control liaison engineer. If a PRR is written, hard copy of MR will be attached to it and forwarded with part to the reworking department or Materials Review, as applicable.
MATERIALS REVIEW AREA
If part is not required for Engineering analysis, Materials Review processes MR as indicated below. Materials Review notifies Engineering Reliability representative upon receipt of MR hard copy and part.
REWORK
If part is to be reworked, it is forwarded with MR hard copy to reworking department.
SCRAP
If part is scrapped, Materials Review will enter any additional information obtained since MR was initially prepared in Rework Report section of MR, and forward it to Quality Control liaison engineer.
REQUIRED BY ENGINEERING
If part is required by Engineering Reliability representative for analysis, he will prepare and process a Transfer Order (Form 39-M-1), as described in SCM P-10L5, Sections VII and VIII. Materials Review will surrender part and MR to him upon receipt of green copy of T.O.
RETURN TO VENDOR
If part is returned to Vendor and a report of his failure analysis is required by Engineering or Quality Control, the MR hard copy will be marked "Vendor's Report Requested" and forwarded to Data and Records.
VENDOR'S REPORT REQUIRED
When a Vendor's report is required by the Engineering Reliability representative or the Quality Control liaison engineer, he will prepare a form AVO addressed to the Rejections Section of Purchasing, describing the rejection and requesting the Vendor's report on same. The MR and PRR numbers will be noted on the AVO, which will be attached to the PRR and forwarded with the part to the Rejections Section. A copy of the AVO will be forwarded to Data Submittal, notifying them of requestor.
REWORK AREA
Production department reworks parts. Inspector in area of rework itemizes actual rework accomplished, notes condition of part, and enters any additional pertinent information in Rework Report section of accompanying MR and forwards it to Quality Control liaison engineer.
QUALITY CONTROL
Quality Control liaison engineer analyzes MR from a Manufacturing and Inspection viewpoint and enters his analysis and action taken in Analysis Report section of MR and forwards to Engineering. If responsible engineer has already entered his analysis and action taken, MR will be forwarded directly to Data and Records. When a vendor's report is received, liaison engineer completes his analysis of initial occurrence and forwards as an addendum to MR to Data and Records.
ENGINEERING
Responsible engineer analyzes MR from an Engineering viewpoint and enters his analyses and action taken in Analysis Report section of MR and forwards to Data and Records. If Quality Control liaison engineer has not yet entered his analysis and action taken, MR will be forwarded to him. When a vendor's report is received, responsible engineer completes his analysis of initial occurrence and forwards as an addendum to MR to Data and Records.
DATA AND RECORDS
Checks accuracy and completeness of MR ditto master, and reproduces and distributes advance information copies as soon as possible to Engineering and Quality Control in accordance with their requirements. Completed MR hard copy will be transcribed onto Form 95-Y-1, reproduced and distributed as soon as possible to affected departments as required. When an MR addendum completing analysis of initial occurrence is received, it will be duplicated and distributed as above.
DATA SUBMITTAL
Sends an AVO to Receiving acknowledging receipt of vendor's report. Forwards two copies of report to requestor, per AVO, and one copy to Data and Records.
VENDOR
Prepares failure analysis report and mails three copies to Data Submittal - Mail.
PURCHASING
Upon receipt of AVO, a Purchase Order with code sheet AVO included, will be forwarded to the vendor requesting his failure analysis report. The P.O. will give the reasons for the rejection as described on the AVO, reference the MR number noted thereon, and require the vendor's reply to reference such MR number. A copy of the P.O. will be forwarded to Data Submittal notifying them of such data requirements.

FIGURE XI



ELECTRONICS FAILURE REPORT--

DATE OF FAILURE	REPORT NO. № 15201		ACTIVITY AND LOCATION		
EQUIPMENT INSTALLED IN (TYPE AND NO.)			REPAIRED OR REPORTED BY (NAME)		DATE
EQUIPMENT (NAME)	MODEL DESIGNATION AND MOD. NO.		SERIAL NO.	CONTRACTOR	CONTR. OR ORDER NO.
MAJOR UNIT (NAME)	MODEL DESIGNATION AND MOD. NO.		SERIAL NO.	CONTRACTOR	CONTR. OR ORDER NO.
ASSEMBLY (NAME)	ASSEMBLY AND MOD. NO.		SERIAL NO.	MANUFACTURER	(LEAVE BLANK)
PART DATA	PART OR TUBE TYPE	MANUFACTURER'S PART NO.	STOCK NO. (IF KNOWN)		SYMBOL DESIGNATION
	HOURS IN SERVICE	MANUFACTURER	SERIAL NO. (IF ANY)		SOURCE OF REPLACEMENT PART

FIRST INDICATION OF TROUBLE
1 ☐ INOPERATIVE
2 ☐ INTERMITTENT
3 ☐ LOW PERFORMANCE
4 ☐ NOISY
5 ☐ OFF FREQUENCY
6 ☐ OUT OF ADJUSTMENT
7 ☐ OVERHEATING
8 ☐ UNSTABLE
9 ☐ OTHER (EXPLAIN)

CHECK TYPE(S) OF PART FAILURE

007 ☐ ARCING	001 ☐ GASSY	790 ☐ OUT OF ADJUSTMENT		5 ☐ FAULTY PACKAGING	
710 ☐ BEARING FAILURE	300 ☐ GROUNDED	005 ☐ SHORTED		6 ☐ MISHANDLING	
780 ☐ BENT	800 ☐ LEAKAGE	770 ☐ SLIP RING OR COMMUTATOR FAILURE		0 ☐ INITIAL TEST	
040 ☐ BINDING	780 ☐ LOOSE	010 ☐ TESTED OK--DID NOT WORK		1 ☐ NORMAL OPERATION	
070 ☐ BROKEN	004 ☐ LOW GM OR EMISSION	020 ☐ WORN EXCESSIVELY		2 ☐ STORAGE OR AGE	
720 ☐ BRUSH FAILURE	780 ☐ MISSING			7 ☐ ASSOC. FAILURE (EXPL.)	
090 ☐ BURNED OUT	005 ☐ NOISY			4 ☐ OTHER (EXPLAIN)	
130 ☐ CHANGED VALUE	450 ☐ OPEN			WAS THE PART REPLACED AS PREVENTIVE MAINTENANCE? YES ☐ NO ☐	
170 ☐ CORRODED	099 ☐ OTHER (EXPLAIN)				

FIGURE XII

field engineers, in which case forms similar to those described may be used. Correlation of this information with that generated internally is sometimes difficult, and complete reliance cannot be placed on most customer generated reports since ordinarily they are not a random distribution. However, we process these with our regular internal reports, coding them for origin.

Before studying the methods employed for stimulating corrective action, some additional report forms are presented which you may study at your leisure and we will not attempt more than a cursory examination of them today. This form, (Fig. XII), has several obvious advantages, the most pronounced being its checkbook size which enables the operator or inspector to carry it in his hip pocket. It also has the desirable effect of directing the thoughts of the reporter along certain specified routes by adopting the check-off principle. It is evident that the value of the information requested on this form would lie in the aggregation of like failures against like parts, rather than the importance that might be derived from a single report.

In Figure XIII we see a somewhat composite type of form which is intended to generate statistical value in addition to generating corrective measures.

Figure XIV is a report used by one of the Services which, in addition to channelling the thoughts of the reporter along a predetermined course, extracts information which can be more closely related to the dollar, such as:

a. Time in service (hours).
b. Was the mission aborted.
c. Repair time.

This type of information is an excellent indicator for gauging the importance of various failures, and directs the corrective action body to an area where their efforts will be most fruitful. The information derived from these three spaces should indeed be exploited to its fullest extent.

MALFUNCTION REPORT

Malfunction Date: _____

Systems:

Ground:
- O A-B-C
- O D-E-G
- O Radio Control
- O Flt Control & Servos
- O _____

Airborne:
- O Guidance System No. _____
- O Flt Control & Servos System No.
- O Radio Control System No. _____
- O Instrumentation
- O

Sub-System: _____

Unit: _____ Serial No.: _____ Time Meter Reading: _____

Plug-in Sub-unit: _____ Function: _____ Serial No.: _____

ITEM*	MFR	DESCRIPTION	ITEM*	MFR	DESCRIPTION
O Tube		(V-)	O Pot		
O Resistor		(R-)	O Stepper		
O Capacitor		(C-)	O Mat Rect		
O Relay		(K-)	O Gyro		
O CR Diode		(CR-)	O		

Location:
- O Guidance Dev Lab
- O Systems Lab
- O "B" Lab
- O "C" Area
- O Tape Prep Lab
- O Flt Control Lab
- O Radio/Radar Lab
- O Instrumentation Lab
- O Missile Simulator Lab
- O

Failure Occurred During:
- O Bench Check
- O Lab Systems Test
- O Environmental Tests
- O Preflight No.
- O Ground Test
- O Flight No. _____
- O

Failure Symptoms
- O Performance Error
- O Intermittent Oper.
- O No Operation
- O Instability
- O Over-Heating
- O Shorted
- O Cross Talk
- O Open
- O Broken
- O Loose
- O Oscillation
- O Arcing
- O Mech. Binding
- O

Description of Events and/or Remarks:

Responsible Engineer: _____ Phone _____

Reported By: _____ Phone _____

FOR RELIABILITY

Date Recv'd.: _____ By: _____

Action Taken:

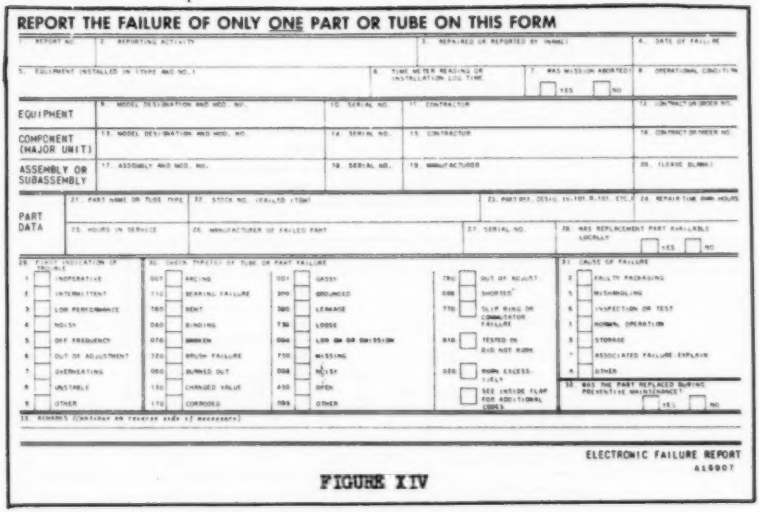
Cause of Failure
- O Design Factor
- O Construction Factor
- O Adjustment Factor
- O Schematic Factor
- O Human Factor
- O Defective from Vendor
- O Premature Wear Out
- O Normal Wear Out
- O Environmental Stress
- O Mechanical Failure
- O Secondary Failure
- O

O Abortive Malfunction O Non Abortive Malfunction

*To be forwarded to Reliability Section for analysis

Reliability Malfunction No.: _____

FIGURE XIII


REPORT THE FAILURE OF ONLY ONE PART OR TUBE ON THIS FORM

1. REPORT NO. | 2. REPORTING ACTIVITY | 3. REPLACED OR REPORTED BY (NAME) | 4. DATE OF FAILURE

5. EQUIPMENT INSTALLED IN (TYPE AND NO.) | 6. TIME METER READING OR INSTALLATION LOG TIME | 7. WAS MISSION ABORTED? YES NO | 8. OPERATIONAL CONDITION

EQUIPMENT	9. MODEL DESIGNATION AND MOD. NO.	10. SERIAL NO.	11. CONTRACTOR	12. CONTRACTOR ORDER NO.
COMPONENT (MAJOR UNIT)	13. MODEL DESIGNATION AND MOD. NO.	14. SERIAL NO.	15. CONTRACTOR	16. CONTRACTOR ORDER NO.
ASSEMBLY OR SUBASSEMBLY	17. ASSEMBLY MOD. NO.	18. SERIAL NO.	19. MANUFACTURER	20. (LEAVE BLANK)

PART DATA

21. PART NAME OR TUBE TYPE | 22. STOCK NO. (FAILED ITEM) | 23. PART NO. (DESIG. BY MIL SPEC. ETC.) | 24. REPAIR TIME (MAN HOURS)

25. HOURS IN SERVICE | 26. MANUFACTURER OF FAILED PART | 27. SERIAL NO. | 28. WAS REPLACEMENT PART AVAILABLE LOCALLY? YES NO

29. FIRST INDICATION OF TROUBLE
1 INOPERATIVE
2 INTERMITTENT
3 LOW PERFORMANCE
4 NOISY
5 OFF FREQUENCY
6 OUT OF ADJUSTMENT
7 OVERHEATING
8 UNSTABLE
9 OTHER

30. CHECK TYPE(S) OF TUBE OR PART FAILURE
007 ARCING
010 BEARING FAILURE
020 DENT
030 BINDING
070 BROKEN
080 BRUSH FAILURE
090 BURNED OUT
130 CHANGED VALUE
170 CORRODED
190 CRACKED
200 GROUNDED
280 LEAKAGE
330 LOOSE
360 LOW EM OR EMISSION
390 MISSING
400 NOISY
450 OPEN
095 OTHER
190 OUT OF ADJUST.
008 SHORTED
770 SLIP RING OR COMMUTATOR FAILURE
010 TESTED IN DID NOT RUN
020 WORN EXCESSIVELY
SEE INSIDE FLAP FOR ADDITIONAL CODES

31. CAUSE OF FAILURE
2 FAULTY PACKAGING
5 MISHANDLING
6 INSPECTION OR TEST
1 NORMAL OPERATION
3 STORAGE
4 ASSOCIATED FAILURE EXPLAIN
9 OTHER

32. WAS THE PART REPLACED DURING PREVENTIVE MAINTENANCE? YES NO

33. REMARKS (CONTINUE ON REVERSE SIDE IF NECESSARY)

ELECTRONIC FAILURE REPORT
AL6907

FIGURE XIV

Next is shown a tabulation, (Fig. XV), displaying the various elements of feedback report forms, and the number of forms upon which each of these elements appear. This has proven beneficial in developing a feedback report form since it indicates the elements which others have considered important in a feedback program.

Although there are hundreds of different types of forms currently in use, and many different concepts, it is interesting to note that as we progress in the field of failure reporting the different concepts are gradually merging into a recognizable pattern. We, therefore, know that if we expect consistency in reporting like failures from the engineer, the technician, the inspector, the operator, or the field service representative, we, the proponents of better failure feedback information must:

a. Determine the information wanted.
b. Stimulate the reporter's thoughts along a predetermined course.

V. FAILURE ANALYSIS

It is indeed a milestone passed when an organization can claim to have a good efficient reporting system, but what has been discussed up to this point has not contributed to improvement of the product. It is extremely important to assure ourselves that this invaluable information is prepared and disseminated in a manner which will encourage better design, better fabrication, and better quality control.

In the case of development articles where we do not have a large homogeneous collection, North American Aviation failure report forms follow a parallel circuit through Quality Control and Design Engineering. Every report is reviewed. All reports are coded on marginal punched cards and sorted for significance, and those which

INFORMATION REQUIRED TO COMPLETE MALFUNCTION REPORT FORMS

FORM	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
FAILED DETAIL	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SYSTEM	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ASSEMBLY	X	X	X	X	X	X	X	X	X	X	X	X			
OPERATING TIME	X	X	X	X	X	X	X	X	X	X	X	X			
COMPONENT	X	X	X	X	X	X	X	X	X	X	X	X			
REMARKS OR COMMENTS	X	X	X	X	X	X	X	X	X	X	X	X			
DISCRIPTION OF TROUBLE	X	X	X	X	X	X	X	X	X	X	X	X			
REFERENCE SYMBOL NUMBER	X	X	X	X	X	X	X	X	X	X	X	X			
FIRST INDICATION OF TROUBLE	X	X	X	X	X	X	X	X	X	X	X	X			
TYPE OF FAILURE	X	X	X	X	X	X	X	X	X	X	X	X			
PLACE OF FAILURE	X	X	X	X	X	X	X	X	X	X	X	X			
SYMPTOMS OF FAILURE	X	X	X	X	X	X	X	X	X	X	X	X			
FAILED DUE TO	X	X	X	X	X	X	X	X	X	X	X	X			
WORK TO CORRECT TROUBLE	X	X	X	X	X	X	X	X	X	X	X	X			
REASON FOR REJECTION	X	X	X	X	X	X	X	X	X	X	X	X			
TYPE OF TEST	X	X	X	X	X	X	X	X	X	X	X	X			
REPAIR TIME	X	X	X	X	X	X	X	X	X	X	X	X			
FINAL DISPOSITION	X	X	X	X	X	X	X	X	X	X	X	X			
RECOMMENDATIONS	X	X	X	X	X	X	X	X	X	X	X	X			
ENGINEERING COMMENTS	X	X	X	X	X	X	X	X	X	X	X	X			
DUPLICATE TYPE FORM	X	X	X	X	X	X	X	X	X	X	X	X			
PREVENTATIVE MAINTENANCE	X	X	X	X	X	X	X	X	X	X	X	X			
SUB-ASSEMBLY	X	X	X	X	X	X	X	X	X	X	X	X			
INITIAL DISPOSITION	X	X	X	X	X	X	X	X	X	X	X	X			
UNDERLYING CAUSE	X	X	X	X	X	X	X	X	X	X	X	X			
ENVIRONMENTAL CONDITIONS	X	X	X	X	X	X	X	X	X	X	X	X			
MACHINE TYPE CARD	X	X	X	X	X	X	X	X	X	X	X	X			
WORK TO LOCATE TROUBLE	X	X	X	X	X	X	X	X	X	X	X	X			
TIME TO LOCATE TROUBLE	X	X	X	X	X	X	X	X	X	X	X	X			
NO NARRATIVE INFORMATION	X	X	X	X	X	X	X	X	X	X	X	X			
TIME OUT OF SERVICE	X	X	X	X	X	X	X	X	X	X	X	X			
ACTION BY RELIABILITY	X	X	X	X	X	X	X	X	X	X	X	X			
DETAIL PART CHECKOFF LIST	X	X	X	X	X	X	X	X	X	X	X	X			

FIGURE XV

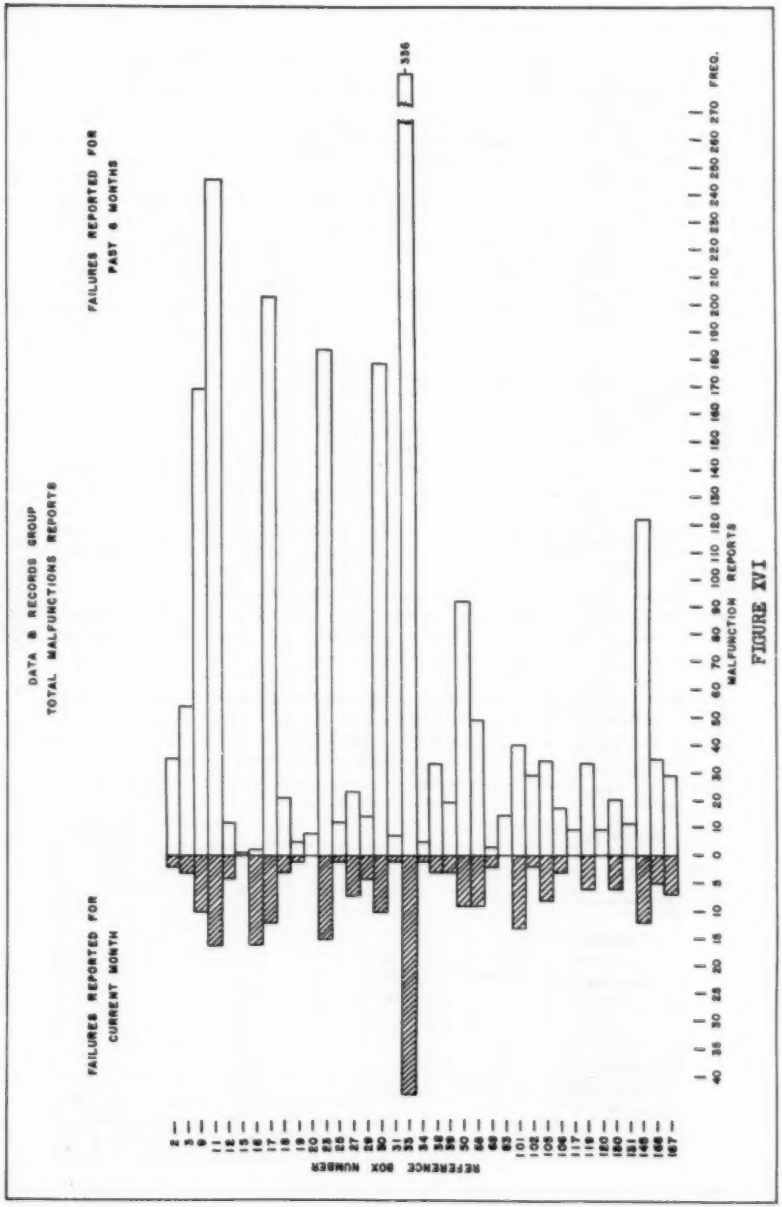

DATA 8 RECORDS GROUP
TOTAL MALFUNCTIONS REPORTS
FAILURES REPORTED FOR CURRENT MONTH
FAILURES REPORTED FOR PAST 6 MONTHS
336
REFERENCE BOX NUMBER
MALFUNCTION REPORTS
FREQ.

FIGURE XVI

GROSS TABULATION OF DETAIL FAILURES

BOX NUMBER		TOTAL FAILURES	FLD. SERV. RPTS.	BOX FAILURES	ACCELEROMETER	AMPLIFIER	BULB	CABLES	CAPACITORS	CHOKES	CHOPPERS	COIL	COVER/SHIELDS	CRYSTALS	DESIGNATOR	FAN, BLOWER	FILTER	FILTER, HAND PASS	FLEX GUIDE	GENERATOR/ MOTOR	GIMBAL/STOP PINS	GLASS/LENS/ REFLECTOR	GYROS	HARNESS	HEATERS	HOOD	INSULATION BOARD	LEVER	MAGNETRON	MANDRELLS	MASK	MICRO-SWITCH	MOD/MOD BOARD	MOD, SUB ASS'Y.	MOUNT	PLUGS/ CONNECTORS	POTENTIOMETER	PULSE FORM NET.	RAW STOCK	REACTOR	RECTIFIER	REF. CIRCLE	RELAY	RESISTOR	RESISTOR BOARD	RESOLVERS	RETICLES/ RESOLATOR	SERVO	STRIPS, IR	SYNCHRONIZERS	TACHOMETER	TRANSFORMERS	TUBES
	2	2																																																					
	3	86	12	21		7			3		15			3																																									
	4	156	12	38					6	1	1			2																																									
	5	228	22	20		1	1		3	1	8	1	3			2		2																																				
	6	18	6	8																																																		
	7	14	4	4			3																																															
	8	1		1																																																	
	9	1																																																			
	10	10							4	1	4			2																																									
	11	3							2																																													
	12	4																																																			
	13	6																																																			
	14	4																																																			
	15	9																																																			
	16	1																																																			
	17	16							4		4			4																																									
	18	3							2																																												
	19	4																																																			
	20	1																																																			
	21	4																																																			
	22	6																																																			
	23	26							1					4			1							3																															
	24	6																																																			
	25	10										2																																									
	26	14																																																			
	27	1																																																			
	28	7																																																			
	29	4																																																			
	30	14					4	1																																													
	31	2																																																			
	32	48	14	12			47		37		9			2			17																																						
	33	6	1	1			11		6					1			1																																					
	34	4		3																																																
	35	15		1			1																	7																													
	36	3																						1																													

FIGURE XVII

appear to be of serious magnitude are investigated by Quality Control or Engineering, depending upon where the area of correction lies. If the statistical group reports a quantity of like failures, a complete investigation follows.

In the production phase where investigative action is the result of several like failures in a homogeneous population, it is essential that whatever medium is used to trigger corrective action, it is prepared and presented in a manner which has the effect of stimulating action. A letter merely pointing out to Engineering, Manufacturing, or Quality Control that we are experiencing an abnormal rate of rejections on a certain part falls far short of being the ideal presentation. Including in the letter such data as quantity, cause and effect, and dollar significance certainly adds immeasurably to the intended effect. Going still further and preparing a graph, histogram or chart showing the quantity and cause with comparison to other related data, is really supplying a tool which will inspire a desire to act.

Some of the more common methods which may be used to display deficiency information are bar charts, graphs, tabulations, frequency distributions, and other graphic methods. One approach which has proven effective is a typical chart, (Fig. XVI), depicting the malfunctions which could have occurred in an assembly area against a fire and flight control system. The numbers on the extreme left represent Black Box numbers; the shaded horizontal bars represent total quantity of malfunctions within the period of the past month; and, the horizontal bars to the right indicate total failures for the previous six months. At a glance, we have evidence that certain Black Boxes are less reliable than others. In Figure XVII, again the Black Box number is in the left hand column, and reading across the chart are the names and frequency of detail components causing the failures. In Figure XVIII, broken down for

AMPLIFIER
PART NUMBER 11609-501
BOX 101

DETAIL	PART NUMBER	REFERENCE SYMBOL	REPORTED MALFUNCTION
Tube	6112	V 10101	Excessive noise
Tube	6112	V 10101	Excessive noise
Tube	6112	V 10101	Noisy
Tube	6112	V 10101	Excessive noise
Tube	6112	V 10101	Excessive noise
Tube	6112	V 10101	Low gain and noisy
Tube	6112	V 10101	Low gain and noisy
Tube	6112	V 10101	Excessive noise
Tube	6112	V 10101	Low gain and noisy
Tube	6112	V 10101	Not reported
Tube	6112	V 10101	Excessive noise
Tube	6112	V 10101	Low gain and noisy

FIGURE XVIII

a single Black Box are the names, quantities, part numbers of the offending details, and their related previously reported malfunction.

We have outlined today the importance of feedback of failure data and have mentioned several systems for providing this information. Various types of forms have been displayed and presentation of the results has been discussed. We have presented more details of flow charts and forms than we could possibly discuss in the limited time available today. However, it is hoped that some of this may prove of value at some later date when you may study these details at leisure.

I wish to emphasize that the results of such a program can only be measured by its effectiveness in increasing the Reliability of the product. A method of assuring that this is being accomplished must be incorporated into any feedback system. The dependence on the human factor was earlier stressed. We still have the human factor with us in final stages of our loop. The author has been convinced that to achieve maximum results in the field of corrective action, the data must be presented in an attractive way, a convincing way, and in a manner which will spotlight the relative importance of the problem. The old adage, "you can lead a horse to water, but you can't make him drink", is really not so far from this problem. You can give a person data, but unless the spark of desire to act is ignited, little will be achieved.

A BLEND OF OPERATIONS RESEARCH AND QUALITY CONTROL IN BALANCING LOADS ON TELEPHONE EQUIPMENT

Howard L. Jones
Illinois Bell Telephone Company

In crossbar types of central offices serving dial telephones, all incoming and outgoing calls are routed through what are called line link frames. These frames carry circuits and related apparatus linking the customers' lines coming into the office with the rest of the equipment in that office. There may be 20 to 40 of these frames in a fully developed office serving approximately 10,000 telephone lines.

Each such frame carries 100 circuits, or line links, divided into 10 horizontal groups of 10 links. Each customer line is assigned to a particular group of 10 links, and a call to or from this line may be made as long as one or more of the 10 links in the group is idle. It is possible that all 10 links may be busy, however, since a group of 10 links may serve a maximum of 19 to 59 lines, depending on the capacity of the frame, and 10 of these lines may actually be in use at a given time. In that case, a call cannot be sent or received over any other line in the group. If someone picks up a receiver connected to one of the other lines, there will be no dial tone to indicate that the equipment is ready for him to dial another number. We call this situation a "dial tone delay." If someone else tries to call him, he will get a busy signal, even though the telephone he is trying to call is not in use. We call an incident of this kind an "overflow."

Both overflows and dial tone delays cause revenue losses to the telephone company. What is worse, they irritate our customers, because the quality of the service falls below the high level they have come to expect. These unpleasant incidents occur most frequently during the busiest part of the day. To avoid having them occur, we try to engineer central office installations so that, even in the busiest hour of the day during the busiest months of the year, the average number of overflows due to busy links will not exceed 2 per cent of the calls attempted, and an average of less than 1-1/2 per cent of the calls made or attempted will result in a dial tone delay exceeding 3 seconds. Moreover, after the office is installed, we try to keep the traffic loads on the various frames in the office more or less in balance so that all customers will receive about the same quality of service. Delays and busy signals may occur for other reasons; but the problems they create are beyond the scope of the study considered here.

The problem to be discussed here is that of finding the balancing procedure which will result in the most efficient use of the line link frames in telephone central offices. The investment in these frames is an important part of the total investment in our dial central offices. While the frames and other central office equipment are originally designed to give a quality of service above the minimum levels mentioned, under a wide variety of operating conditions, some economies may be realized by studying the conditions in each office subsequent to the original installation and using these studies in planning future additions to the equipment.

The study of such conditions was a major part of the functions of a Central Office Utilization Subcommittee composed of representatives of

the various departments of Illinois Bell Telephone Company in our Chicago Area. This Subcommittee was itself a part of an interdepartmental General Facilities Committee, which was organized to study ways to make more efficient use of all property employed in the company's operations.

The subcommittee's approach in studying line link frames might be summarized under four steps, as follows:

1. Getting factual data to measure the quality of the service actually rendered.
2. Experimenting in two central office buildings to determine the effect of various conditions on the quality of service.
3. Using the statistical approach to interpret the data obtained.
4. Recommending procedures for providing acceptable service at minimum cost.

The purpose of this paper is to outline some of the statistical features of the problem and the recommended solution that is now being tried in several telephone central offices. These features include techniques that are employed in the fields of operations research, quality control, applied statistics, telephone engineering, and business administration.

POSSIBLE MEASURES OF QUALITY OF SERVICE

One of the early questions that faced the subcommittee was how to measure the quality of service. In other words, what proportions of the calls routed through a particular crossbar central office, or a particular line link frame in that office, are affected by dial tone delays; and what proportions are affected by overflows? How could we accurately determine what these proportions were?

Various means of getting answers to this question were considered by the subcommittee. Among these, the following might be mentioned:

1. Service observing procedures.
2. Dial tone speed registers.
3. Controller delay registers.
4. Originating peg count registers.
5. Traffic usage recorders.
6. Holding time recorders.
7. Line link load registers.
8. Terminating peg count registers.

None of these devices for measuring the quality of service at the line link frame is completely satisfactory in every respect. Thus service observing procedures are designed to reflect average conditions in all types of central offices, and not busy-hour conditions in crossbar dial offices. Dial tone speed registers, and controller delay registers to some extent, do provide a count of the number of delays on calls originating over customer lines directly served by the central office equipment involved. These delays can be compared with the number of such calls as counted by the originating peg count registers. A controller delay may involve more than one dial tone delay, however; and it may involve any one of several line link frames. The number of such delays is therefore not very useful in locating sources of trouble when it occurs. The dial tone speed register is usually connected to but one

group of links in a frame, since each group observed makes one less subscriber line available for normal use. Both the controller delay register and the dial tone speed register have the additional disadvantage that they measure only overloaded conditions of the equipment, and reflect underloaded conditions only in a negative way that is very imprecise. The traffic usage recorder is a new development of the Bell Telephone Laboratories, and was not available at the time the subcommittee initiated its studies.

The holding time recorder was used to some extent in our studies. As locally developed, this device can be connected so as to scan as many as 60 links in a frame every 12 seconds and count the number of links that are busy. Two recorders can provide data as to the number of busy links for an entire frame of 100 links over the period during which they are connected. In an hour's time, there will be 300 observations of each of these 100 links, and the average ratio of busy links to total links for the frame can be computed to a high degree of precision by dividing the recorded number of busy links by 30,000.

The ratio of busy links to total links for a particular frame is a very useful ratio, for several reasons. One reason is that it can be easily converted into hundred-call-seconds of use per hour; for example, if the ratio of busy links to total links is .35, the hourly traffic load in units of hundred-call-seconds is 12.6 per link, 126 per group of 10 links, and 1260 for a frame of 100 links. This unit of measurement, abbreviated as ccs, is generally used by telephone engineers to measure traffic loads; and much of the subcommittee's discussion of loads was in terms of these units. New crossbar central offices have generally been engineered so that the line link frames will carry an expected load of 1260 ccs units.

The principal objection to the use of holding time recorders is the cost. Normally, there is just one holding time recorder in a building that houses three or four central offices, and the recorder is used for other purposes besides measuring the traffic loads on line link frames. Connecting one of these recorders to 60 of the links on a frame requires expensive circuit changes, and would be too costly for normal use in measuring the quality of service at the frames. During the studies made by the Central Office Utilization Subcommittee, however, there were times when three or four holding time recorders were in use at one of the central offices studied.

The terminating peg count register counts the number of times incoming calls intended for customer lines served by a line link frame actually get as far as that frame, whether they get all the way to the customers' lines or not. The line link load register counts the number of times as many as some predetermined number of links, out of the 10 per horizontal group, are busy when an incoming call reaches the frame, whether completed or not. Hence, if the line link load register were set to operate only when all 10 links in a group were busy, we could get a direct count of the number of overflows due to busy links. Moreover, by dividing the number of registrations on the line link load register by the number of registrations on the terminating peg count register, we could obtain the percentage of the terminating calls that result in overflows due to busy links. This is one of the percentages that was of particular interest to the subcommittee.

Experience indicates, however, that percentages obtained in this way are frequently so small and vary so widely that they are unreliable for estimating overall averages, or in determining how much more traffic a line link frame can carry without too much deterioration in the quality of the service. For this reason, prior to the study covered by this paper, the line link load registers had been set to operate when as many as 8 of the 10 links in a group were busy at the time an incoming call is received. With this setting, it was felt that the percentages obtained by dividing load registrations by terminating peg count registrations provided a better guide to overloaded situations than the percentages obtained when the registers were set to operate when all 10 links in a group were busy.

ESTIMATING TRAFFIC LOADS WITH LINE LINK LOAD REGISTERS

Line links are like many other types of telephone equipment in that the number of customers served exceeds the number of circuits provided. Other types of common equipment of this kind are the telephone trunks between central offices and between one city and another, as well as much of the equipment in the central offices themselves. The problems of providing enough common equipment of these various types are problems in what is now called queuing theory, or the theory of waiting lines, by people in operations research.

The problems in queuing theory are about as old as the telephone itself. In solving them, use is made of the Poisson distribution to compute the percentage of the time all the equipment of a certain type will be in use under each one of various load conditions. The results of computations of this kind are issued in the form of tables that tell how many circuits to provide under these various conditions in order to provide service at an acceptable quality level.

It occurred to one of our engineers, Mr. R. S. Hubbell, that if the Poisson distribution could be used to predict the number of times all 10 links in a horizontal group were busy for a given traffic load as measured in ccs units, then it ought to be possible to estimate the traffic load by observing the number of times a certain number of links were busy. In other words, the percentage obtained by dividing the number of times the line link load register scores by the number of times the terminating peg count register scores could be used to estimate the underlying traffic load as measured in ccs units. Moreover, he thought that the estimates would be most reliable if the load registers were set to operate when as many as 3 or 4 links out of 10 were busy, or about the average number of links that would actually be busy. With these thoughts in mind, Mr. Hubbell was largely instrumental in having the load registers in the central offices being studied set to operate when as many as 4 links out of 10 were busy. He then raised the question as to how the data thus obtained could actually be converted into traffic loads in ccs units.

Such conversion can easily be made, of course, provided the distribution of the number of busy links is stable and actually conforms to the Poisson distribution. In that case, we can not only estimate the traffic load in ccs units, but we can also estimate the percentage of overflows due to busy links, by using the relationships shown in Table 1. In this table, the argument shown in column (a) represents the average number of busy links per horizontal group of 10 links. Column (b) shows the cor-

responding traffic load in ccs units for a frame of 100 links. It is obtained by multiplying the entry in column (a) by 360. Column (c) shows the corresponding percentage of line link load registrations to terminating peg count. Column (d) shows the corresponding probability, expressed

TABLE 1

RELATIONSHIP BETWEEN AVERAGE TRAFFIC LOADS, OVERFLOWS, AND PERCENTAGES OF LINE LINK LOAD REGISTRATIONS TO TERMINATING PEG COUNTS

Average No. of Busy Links per Group of 10 (a)	Traffic Load in ccs Units for Frame (b)	Per Cent L.L.Load to Peg Count (c)	Per Cent Probability of an Overflow (d)
2.0	720	14.29	0.00
2.1	756	16.14	0.01
2.2	792	18.06	0.01
2.3	828	20.07	0.01
2.4	864	22.13	0.02
2.5	900	24.24	0.03
2.6	936	26.40	0.04
2.7	972	28.59	0.05
2.8	1008	30.81	0.07
2.9	1044	33.04	0.09
3.0	1080	35.28	0.11
3.1	1116	37.52	0.14
3.2	1152	39.75	0.18
3.3	1188	41.97	0.22
3.4	1224	44.16	0.27
3.5	1260	46.34	0.33
3.6	1296	48.48	0.40
3.7	1332	50.58	0.48
3.8	1368	52.65	0.58
3.9	1404	54.68	0.69
4.0	1440	56.65	0.81
4.1	1476	58.58	0.95
4.2	1512	60.46	1.11
4.3	1548	62.28	1.29
4.4	1584	64.06	1.49
4.5	1620	65.77	1.71
4.6	1656	67.43	1.95
4.7	1692	69.03	2.22
4.8	1728	70.58	2.51
4.9	1764	72.07	2.83
5.0	1800	73.50	3.18

as a percentage, that all 10 links in a group will be busy, and hence the probability of an overflow. Column (d) is also the probability of a dial tone delay due to busy links; but this refers to all delays, and not just delays in excess of 3 seconds. Columns (c) and (d) were obtained by entering E. C. Molina's Table II of Poisson's Exponential Binomial Limit with $\underline{a}$ equal to the value shown in our Table 1, and then writing down the values shown for c equal to 4 and 10, after multiplying by 100 to express the probability as a percentage.

TABLE 2
LINE LINK FRAME LOAD CONVERSION TABLE
PER CENT LOAD - CCS UNITS

%	CCS	%	CCS	%	CCS	%	CCS	%	CCS
.5	241	20.5	836	40.5	1164	60.5	1513	80.5	2002
1.0	295	21.0	845	41.0	1173	61.0	1523	81.0	2018
1.5	335	21.5	853	41.5	1181	61.5	1533	81.5	2035
2.0	365	22.0	862	42.0	1189	62.0	1543	82.0	2053
2.5	390	22.5	870	42.5	1197	62.5	1553	82.5	2071
3.0	414	23.0	879	43.0	1205	63.0	1563	83.0	2088
3.5	437	23.5	888	43.5	1213	63.5	1573	83.5	2106
4.0	456	24.0	896	44.0	1222	64.0	1584	84.0	2125
4.5	475	24.5	904	44.5	1230	64.5	1594	84.5	2146
5.0	492	25.0	913	45.0	1238	65.0	1604	85.0	2165
5.5	508	25.5	922	45.5	1247	65.5	1615	85.5	2185
6.0	524	26.0	930	46.0	1255	66.0	1625	86.0	2206
6.5	538	26.5	938	46.5	1263	66.5	1636	86.5	2229
7.0	552	27.0	947	47.0	1271	67.0	1647	87.0	2252
7.5	566	27.5	955	47.5	1279	67.5	1658	87.5	2275
8.0	578	28.0	963	48.0	1288	68.0	1669	88.0	2299
8.5	591	28.5	971	48.5	1296	68.5	1680	88.5	2323
9.0	603	29.0	979	49.0	1304	69.0	1692	89.0	2349
9.5	616	29.5	987	49.5	1313	69.5	1703	89.5	2377
10.0	628	30.0	995	50.0	1322	70.0	1715	90.0	2405
10.5	639	30.5	1003	50.5	1330	70.5	1727	90.5	2434
11.0	650	31.0	1011	51.0	1339	71.0	1739	91.0	2466
11.5	662	31.5	1019	51.5	1348	71.5	1751	91.5	2498
12.0	673	32.0	1028	52.0	1357	72.0	1763	92.0	2532
12.5	684	32.5	1036	52.5	1366	72.5	1775	92.5	2569
13.0	694	33.0	1044	53.0	1375	73.0	1788	93.0	2609
13.5	704	33.5	1052	53.5	1384	73.5	1800	93.5	2650
14.0	714	34.0	1060	54.0	1393	74.0	1813	94.0	2694
14.5	724	34.5	1068	54.5	1402	74.5	1826	94.5	2739
15.0	734	35.0	1076	55.0	1411	75.0	1839	95.0	2790
15.5	743	35.5	1084	55.5	1420	75.5	1853	95.5	2848
16.0	753	36.0	1092	56.0	1429	76.0	1868	96.0	2913
16.5	763	36.5	1099	56.5	1438	76.5	1882	96.5	2981
17.0	772	37.0	1107	57.0	1447	77.0	1896	97.0	3062
17.5	781	37.5	1115	57.5	1456	77.5	1910	97.5	3158
18.0	791	38.0	1123	58.0	1465	78.0	1925	98.0	3269
18.5	800	38.5	1131	58.5	1475	78.5	1940	98.5	3415
19.0	809	39.0	1139	59.0	1484	79.0	1954	98.97	3600
19.5	818	39.5	1148	59.5	1493	79.5	1970		
20.0	827	40.0	1156	60.0	1503	80.0	1985		

Table 2 shows the same relationship as in Table 1, except that the argument is now the probability that 4 or more links are busy, this probability being shown in steps of 1/2 of 1 per cent. This table was prepared by one of our traffic supervisors, Mr. G. P. Williams, by interpolating in Molina's tables. It is now being used in Chicago No. 1 crossbar dial offices to convert register readings to ccs units. The registers are connected to a timing device that allows them to operate only during the busiesthour of the day. This hour is between 10 and

11 A.M. in most of our central offices.

To illustrate how Table 2 is used, let us consider a concrete example. For Line Link Frame No. 5 in our Beverly office building, the terminating peg count of the number of incoming calls for the busy hour 10 to 11 A.M. on September 20, 1954, was 133. The number of times as many as 4 line links in a group of 10 were busy during this hour, as recorded by the line link load register, was 41. Dividing 41 by 133, we get .308, or 30.8 per cent. Referring to Table 2, we see that the closest figure to 30.8 per cent in the table is 31.0 per cent. The number of ccs units corresponding to 31.0 per cent is 1011. Hence, the estimated number of ccs units during that particular busy hour is 1011.

RELIABILITY OF THE ESTIMATES OF TRAFFIC LOADS

The estimates of traffic loads obtained by employing Table 2 are based on a simple probability model. But when we use mathematical models, including probability models, to help solve management problems, we have to keep in mind that the model is usually only a rough approximation to the actual situation. The better the approximation, the more reliable and more useful will be the conclusions reached by interpreting data in terms of the model.

For the problem we are discussing here, there are several models that might be considered. Two of these models, referred to as Model No. 1 and Model No. 2, are discussed in the appendix to this paper. Tables 1 and 2 are based on Model No. 1, which is the simpler of the two.

The reason we are interested in analyzing these models is that we want to find useful answers to questions like these:

1. How can we best use data that are available, or can be made available, to estimate the average traffic load on a line link frame?
2. Will the estimates tend to be too high or too low, on the average? As a statistician would put it, "Will the estimates be biased?"
3. How much will the estimates vary when the period covered by the register readings is limited to an hour, or possibly 5 or 10 hours? In statistical language, "What is the standard deviation of the estimates, and how is it related to the number of observations?"
4. What is the optimum setting of the load register? Should it be set to operate when as many as 3 links are busy, as many as 4 links, or some other number of links? The answer should take into consideration both the bias and the standard deviation of the estimates.

For Model No. 1--that is, for the probability model underlying Tables 1 and 2--formulas for the bias and standard deviation of the traffic loads can be derived, as shown in the appendix. These formulas are shown in Table 3. The formula for the standard deviation of the estimate of the probability that k or more links will be busy is of the familiar form

$$\sigma_p = \sqrt{\frac{p'(1 - p')}{n}} ,$$

where P' is the true probability, and n is the number of observations (that is, the number of terminating calls recorded). The formulas for the bias and standard deviation of the average number of busy links, and of the traffic load in ccs units, are approximations.

TABLE 3
BIAS AND STANDARD DEVIATION
OF ESTIMATES BASED ON MODEL NO. 1

Probability that k or more links will be busy:	
Bias	None
Standard deviation	$\sqrt{\frac{P'_k(1 - P'_k)}{n}}$
Average number of busy links:	
Bias	$\frac{P'_k(1 - P'_k)}{2n} \quad \frac{p'_{k-1} - p'_{k-2}}{(p'_{k-1})^3}$
Standard deviation	$\sqrt{\frac{P'_k(1 - P'_k)}{n(p'_{k-1})^2}}$
Traffic load on 10 links in ccs units:	
Bias	$\frac{18P'_k(1 - P'_k)}{n} \quad \frac{p'_{k-1} - p'_{k-2}}{(p'_{k-1})^3}$
Standard deviation	$\sqrt{\frac{(36)^2 P'_k(1 - P'_k)}{n(p'_{k-1})^2}}$

Explanation of Symbols:

P'_k = probability that k or more links are busy at a particular observation,
p'_k = probability that exactly k links are busy at a particular observation,
n = number of observations.

Since the formulas in Table 3 are shown for the general case where the load register is set to record when k or more links are busy, without specifying k, it is possible to determine the approximate range of traffic loads for which a given setting of the load registers will give the best estimates. It turns out that the setting k = 4 (where the load register scores when as many as 4 links are busy) is the optimum setting with respect to the bias in the estimates when the traffic per group of 10 links is from 91 to 126 ccs units, inclusive. In other words, when the load register is set to operate when as many as 4 links are busy, the bias in the estimates is less than that for any other setting, provided

the traffic load is between 91 and 126 ccs units. The standard deviation of the estimates is minimum for this setting when the traffic loads are between 99 and 133 ccs units. Since the line link frames are usually engineered to carry a maximum load of 126 ccs units per group of 10 links, the setting k = 4 appears to be about right.

TABLE 4
COMPARISON OF ESTIMATES OF TRAFFIC LOADS IN CCS UNITS
LINE LINK FRAME #1-B, BEVERLY BUILDING

Hour and Dates of Observations	Sum of Estimates Based on Table 2 Weekly	Cum.	Sum of Est. Based on Holding Time Rec. Weekly	Cum.	Per Cent of Difference Weekly	Cum.
10:00 AM to 11:00 AM						
9-20-54 to 9-24-54	5,895	5,895	6,176	6,176	-4.55	-4.55
9-27-54 to 10-1-54*	5,116	11,011	5,083	11,259	0.65	-2.20
9:45 AM to 10:45 AM						
10-11-54 to 10-15-54	7,094	18,105	6,984	18,243	1.58	-0.76
10-18-54 to 10-22-54	6,019	24,124	6,191	24,434	-2.78	-1.27
10-25-54 to 10-29-54	5,743	29,867	5,871	30,305	-2.18	-1.45
11-1-54 to 11-5-54	5,143	35,010	5,338	35,643	-3.65	-1.78
11-15-54 to 11-19-54*	4,571	39,581	4,679	40,322	-2.31	-1.84
11-22-54 to 11-26-54*	5,172	44,753	5,532	45,854	-6.51	-2.40
11-29-54 to 12-3-54	6,782	51,535	6,967	52,821	-2.66	-2.43
12-13-54 to 12-17-54	6,826	58,361	6,935	59,756	-2.37	-2.33
12-20-54 to 12-24-54	5,933	64,294	6,195	65,951	-4.23	-2.51
12-27-54 to 12-31-54	7,416	71,710	7,353	73,304	0.86	-2.17

* Observations covered only 4 days instead of usual 5 days.

TABLE 4A
COMPARISON OF ESTIMATES OF TRAFFIC LOADS IN CCS UNITS
LINE LINK FRAME #2-B, LAKEVIEW BUILDING

Hour and Dates of Observations	Sum of Estimates Based on Table 2 Weekly	Cum.	Sum of Est. Based on Holding Time Rec. Weekly	Cum.	Per Cent of Difference Weekly	Cum.
10:00 AM to 11:00 AM						
10-1-54	827	827	858	858	-3.61	-3.61
10-11-54 to 10-15-54	4,496	5,323	4,389	5,247	2.44	1.45
10-18-54 to 10-22-54	4,404	9,727	4,531	9,778	-2.80	-0.52
10-25-54 to 10-29-54	5,104	14,831	5,262	15,040	-3.00	-1.39
11-1-54 to 11-5-54	4,821	19,652	5,079	20,119	-5.08	-2.32
11-15-54 to 11-19-54	4,485	24,137	4,814	24,933	-6.83	-3.19
11-22-54 to 11-26-54*	3,942	28,079	4,277	29,210	-7.83	-3.87
11-29-54 to 12-3-54	4,249	32,328	4,868	34,078	-12.72	-5.14
12-13-54 to 12-17-54	4,721	37,049	4,925	39,003	-4.14	-5.01
12-20-54 to 12-24-54	4,546	41,595	4,768	43,771	-4.66	-4.97
12-27-54 to 12-31-54	4,669	46,264	5,029	48,800	-7.16	-5.20

* Observations covered only 4 days instead of 5 days.

TABLE 4B
COMPARISON OF ESTIMATES OF TRAFFIC LOADS IN CCS UNITS
LINE LINK FRAME #3-C, ROGERS PARK BUILDING

Hour and Dates of Observations	Sum of Estimates Based on Table 2 Weekly	Cum.	Sum of Est. Based on Holding Time Rec. Weekly	Cum.	Per Cent of Difference Weekly	Cum.
9:45 AM to 10:45 AM						
12-9-54 to 12-10-54	2,935	2,935	2,843	2,843	3.24	3.24
12-13-54 to 12-17-54*	4,066	7,001	3,937	6,780	3.28	3.26
12-20-54 to 12-24-54	5,672	12,673	5,922	12,702	-4.22	-0.23
12-27-54 to 12-31-54	7,044	19,717	6,927	19,629	1.69	0.45
1-6-55 and 1-7-55	2,759	22,476	2,819	22,448	-2.13	0.12
1-10-55 to 1-14-55	7,226	29,702	7,049	29,497	2.51	0.69
1-17-55 to 1-21-55	6,489	36,191	6,295	35,792	3.08	1.11
1-24-55 to 1-28-55	6,529	42,720	6,483	42,275	0.71	1.05
1-31-55 to 2-4-55	6,456	49,176	6,139	48,414	5.16	1.57
2-7-55 to 2-11-55	7,023	56,199	6,639	55,053	5.78	2.08
2-14-55 to 2-18-55	6,587	62,786	6,321	61,374	4.21	2.30
2-21-55	1,156	63,942	1,167	62,541	-0.94	2.24
3-2-55 to 3-4-55	3,972	67,914	3,983	66,524	-0.28	2.09
3-7-55 to 3-11-55	6,387	74,301	6,057	72,581	5.45	2.37
3-14-55 to 3-18-55	6,230	80,531	5,943	78,524	4.83	2.56
3-21-55 to 3-25-55	7,126	87,657	6,704	85,228	6.29	2.85
3-28-55 to 4-1-55	6,511	94,168	6,222	91,450	4.64	2.97
4-4-55 to 4-8-55**	4,862	99,030	5,119	96,569	-5.02	2.55
4-11-55 to 4-15-55	7,535	106,565	7,220	103,789	4.36	2.67
4-18-55 to 4-22-55	6,988	113,553	6,676	110,465	4.67	2.80
4-25-55 to 4-29-55	6,329	119,882	6,531	116,996	-3.09	2.47
5-2-55 to 5-6-55	6,637	126,519	6,569	123,565	1.04	2.39
5-9-55 to 5-13-55	6,955	133,474	6,854	130,419	1.47	2.34
5-16-55 to 5-20-55	6,914	140,388	6,852	137,271	0.90	2.27
5-23-55 to 5-27-55	6,173	146,561	6,393	143,664	-3.44	2.02
6-2-55 and 6-3-55	2,549	149,110	2,544	146,208	0.20	1.98
6-6-55 to 6-10-55	7,117	156,227	7,024	153,232	1.32	1.95
6-13-55 to 6-17-55	6,880	163,107	6,585	159,817	4.48	2.06
6-20-55 to 6-24-55	6,904	170,011	6,832	166,649	1.05	2.02
6-24-55 to 7-1-55	6,210	176,221	6,276	172,925	-1.05	1.91
7-5-55 to 7-8-55	5,173	181,394	5,101	178,026	1.41	1.89

* Observations covered only 3 days instead of usual 5 days.
** Observations covered only 4 days instead of usual 5 days.

The conclusion just stated rests on the assumption that Model No. 1 corresponds to the actual situation. As a matter of fact, the other model considered, here referred to as Model No. 2, seems more realistic. Unfortunately, it is much more difficult to analyze than Model No. 1. Principally for this reason, we make our estimates of traffic loads on the basis of Model No. 1. As a part of the work of the Central Office Utilization Subcommittee, however, studies were made to determine experimentally the actual reliability of the estimates of traffic loads.

In these studies, holding time recorders were connected to one frame in each of the two experimental offices, and subsequently to a frame in a

third office. For each frame studied, the traffic load was computed each day for the busiest hour on the basis of the data obtained from the holding time recorder. Comparison was then made with the estimate obtained by using Table 2. The results of the comparisons, summarized by weeks, are shown in Tables 4, 4A, and 4B. The last percentage shown in each of these tables appears to represent the average bias in the estimates, since the holding time recorders should yield estimates with no bias at all, and with small sampling errors. For the periods covered by the studies, then, our best estimates of the bias in the daily computations of the traffic loads on three frames studied in Beverly, Lakeview, and Rogers Park buildings are -2.17%, -5.20%, and +1.89%, respectively.

Table 5 shows the comparison between these figures and the theoretical bias computed from the formulas in Table 3. The observed bias is many times larger than the theoretical bias, and is in the opposite direction for one of the three frames studied. The results are not too surprising. In fact, we are pleased that the observed bias turned out no worse than the figures shown in Table 5. We had thought the bias might be larger in view of the unrealistic nature of some of the assumptions incorporated in Model No. 1 on which the computations of the traffic loads from Table 2 are based.

TABLE 5
COMPARISON BETWEEN THEORETICAL AND OBSERVED BIAS IN ESTIMATES OF TRAFFIC LOADS

Central Office Building	Theoretical Bias	Observed Bias
Beverly	0.08%	-2.17%
Lakeview	-0.06%	-5.20%
Rogers Park	0.07%	1.89%

The experimental results indicate that the bias may be positive in certain situations and negative in others, and that the size or direction of the bias can not be predicted on the basis of Model No. 1. These results are not necessarily typical of all crossbar offices, since the number of frames studied was very small, and the frames were not selected at random. In the light of our present knowledge, or lack of it, the bias for any particular frame, even in the same building as the frames covered by our studies, can not be determined without making a special study of that frame. Moreover, the results of any such study might not be indicative of the situation at a different time of the day, at a different season of the year, or in a subsequent year after there have been substantial changes in the composition or characteristics of the subscriber lines served by the frame.

On the other hand, a considerable bias in the estimates may not seriously detract from their usefulness as an aid in balancing line link frames. When the estimates are too high, it means that 4 or more links are busy for a higher proportion of the incoming calls than one would predict on the basis of the traffic loads in ccs units. But in a situation of this kind, 10 or more links are likely to be busy a higher proportion of the time than the traffic loads would indicate. For this reason, the estimates may be a better indication of the quality of ser-

vice, with respect to both overflows and dial tone delays, than the actual traffic loads in ccs units.

SOURCES OF TRAFFIC LOADS BY CLASSES OF SERVICE

When a crossbar central office is installed, the traffic loads are distributed over the line link frames as evenly as possible. As an aid to bringing about this even distribution, the subscriber lines to be served by a typical Chicago office are first divided into four classes--(1) P.B.X. (private branch exchange) lines, (2) other business lines, (3) residence individual lines, and (4) residence party lines--and each frame is then assigned the same number of lines in each class as nearly as practicable. Studies are also made to compute a load factor for each class, this factor representing the average traffic load for that class during the busy hour of the day. These load factors assist in equalizing the loads on the various frames. They are subsequently used in reassigning the lines to the different frames when such reassignment becomes necessary to bring the loads on the different frames into better balance. Separate computations of the load factors are made for each central office building, and revisions are made from time to time.

Early in the study of estimates of traffic loads on the basis of Table 2, the question arose as to how these estimates compared with estimates based on the load factors. Mr. G. P. Williams, who participated in the work of the Central Office Utilization Subcommittee, raised the specific question as to how to compute a coefficient of correlation between the two kinds of estimates. In answering this question, we suggested that the coefficient might be more meaningful if the load factors were computed from the data themselves, by employing multiple regression analysis. Mr. Williams, in turn, suggested that computations of this kind would be useful in other ways, since the load factors then in use were necessarily based in part on data obtained before the conversion to dial operation. Any procedure that would eliminate the necessity of relying in part on obsolete data would be very welcome.

The principal work in computing the load factors by regression analysis consisted in finding and summing several thousand squares and cross products. This work was performed by the Surveys Group in our Chief Statistician's office, using I.B.M. equipment. The sums were used in setting up and solving 4 equations in 4 unknowns, as discussed in Section 3 of the appendix. The results are shown in Table 6. Comparison is made with load factors, based on engineering analysis, that were in use at the time of the study.

Most of the factors computed from the regression analysis are a little lower than those computed by engineering analysis. The factors computed by engineering analysis, however, are intended to reflect conditions during the busy winter months. To serve the same purpose, the factors computed by regression analysis should be computed from data for those same months.

The analysis rests on the assumption that the usage per line for a given class of service is the same from frame to frame except for random differences. In view of this assumption, it would seem best to make separate computations for each separate central office building. It should also be observed that the technique works best when there is con-

siderable variation from frame to frame in the distribution of the number of subscriber lines by classes of service. If the various classes were represented in exactly the same proportions from frame to frame, the technique would fail. If the proportions tend to be almost the same for any two classes of service, the computed load factors for these two classes of service will be unstable, and one of them might even turn out to be negative. For this reason, every estimate of the load per line should be accompanied by an estimate of its precision or standard error, which can be computed from the same data used to compute the estimate. A fortunate circumstance is that situations where the distribution of the various classes of service among the frames is so nearly even as to lead to large errors in the estimated load factors are likely to be situations where the frames are already evenly balanced with respect to these classes and the errors are therefore of minor importance.

TABLE 6
COMPARISON BETWEEN LOAD FACTORS COMPUTED BY REGRESSION ANALYSIS AND THOSE COMPUTED BY ENGINEERING ANALYSIS

Building and Class of Service	Load Factors Computed by Regression Analysis	Load Factors Computed by Engineering Analysis
Beverly Building		
Business Lines		
PBX	7.83	9.63
Other	3.71	4.29
Residence Lines		
Individual	4.04	3.15
Party	2.69	3.30
Lakeview Building		
Business Lines		
PBX	10.47	9.45
Other	3.49	3.67
Residence Lines		
Individual	2.05	2.77
Party	1.97	2.14

ANALYSIS OF VARIANCE

In using estimates of traffic loads to equalize the actual loads on the different frames in a central office, we need to know the sources of variation in the estimates. As in many other problems of quality control, the statistical technique known as the analysis of variance is helpful in detecting these sources and evaluating their importance. The theory underlying the application to this particular problem is discussed in Section 3 of the appendix to this paper. The computations are discussed in Section 4.

Table 7 shows the analysis of variance, in the usual form, for Beverly office building. It contains a column showing the number of degrees of freedom associated with each sum of squares, and another column

obtained by dividing the sum of squares by the number of degrees of freedom. Note that the "unexplained" variance per degree of freedom is 19,310.

TABLE 7
ANALYSIS OF VARIANCE OF ESTIMATED TRAFFIC LOADS
BEVERLY OFFICE, MAY 8, 13, AND 22, 1954

Source of Variance	Sum of Squares	Degrees of Freedom	Variance per Degree of Freedom
1. Differences between frames in expected traffic loads	953,413	3	317,804
2. Other differences between frames	671,030	28	23,965
3. Total differences between frames	1,624,443	31	52,401
4. Differences between days	547,595	2	273,797
5. Total "explained" differences	2,172,038	33	65,819
6. Unexplained differences	1,197,227	62	19,310
7. Total differences	3,369,265	95	35,466

If the unexplained variance is due to chance causes, it will tend to make the variance ascribed to other sources larger than they ought to be. In other words, the variance due to chance causes is actually not all shown on the line for item 6 in Table 7, but tends to be distributed over all the items in proportion to the number of degrees of freedom, on account of the random errors in the estimates of the effect of each source of variance.

For our purposes here, it is useful to redistribute the variance as shown in Table 8. In this table, the variance due to chance causes was redistributed by multiplying 19,310 by the number of degrees of freedom. The remainder obtained by subtracting the estimated variance due to chance causes from the total sum of squares is the portion of the total variance that is estimated to be due to nonrandom causes. These nonrandom causes are usually designated as assignable causes.

In constructing a table like Table 8, it sometimes happens that the estimated variance due to chance causes, computed for some line of the table, exceeds the total sum of squares for that line. In situations of that kind, it is suggested that this particular line be omitted from the

table, and that the related sum of squares originally shown on that line be included on the line for "unexplained differences."

TABLE 8
REDISTRIBUTION OF VARIANCE IN ESTIMATES OF TRAFFIC LOADS
BEVERLY OFFICE, MAY 8, 13, AND 22, 1954

Source of Variation	All 96 Observations			Per Observation	
	Sum of Squares	Chance Causes	Assignable Causes	Chance Causes	Assignable Causes
1. Difference between frames in expected traffic loads.....	953,413	57,930	895,483	604	9,328
2. Other differences between frames.....	671,030	540,680	130,350	5,632	1,358
3. Total differences between frames.....	1,624,443	598,610	1,025,833	6,236	10,686
4. Difference between days.....	547,595	38,620	508,975	402	5,302
5. Total "explained" differences.....	2,172,038	637,230	1,534,808	6,638	15,988
6. Differences between observed average & true average.....	19,310	19,310	-	201	-
7. Unexplained differences....	1,197,227	1,197,227	-	12,471	-
8. Total differences....	3,388,575	1,853,767	1,534,808	19,310	15,988

One of the uses to which we can put the data in Table 8 is in determining the effect of the number of observations on the accuracy of the load factors like those shown in Table 6. Thus, for these particular factors, the standard deviation of the sampling errors in these estimates of the average load per frame, in ccs units, will be about

$$\sqrt{\frac{4 \times 19,310}{96}} = \sqrt{805}, \text{ or } 28.3.$$

In addition to this sampling error, the estimates of the traffic load for a particular frame will have a bias, due to the difference between the

average traffic load per subscriber line by classes of service for that frame and the average traffic load per subscriber line by classes for all 32 frames combined. The average effect of this bias is about equal to the square root of 1,358, or 37 ccs units. If the observations covered J busy hours, instead of 3, the square root of the average square of the errors in the estimated traffic loads would appear to be about equal to

$$\sqrt{1358 + \frac{3 \times 805}{J}} .$$

Obviously, the gain in accuracy obtained by observing more than 3 hours is not very great.

Another use to which the data in Table 8 can be put is in measuring the relative importance of different sources of variation as a guide to controlling these sources. Of the total variance of 15,988 per observation that appears to be due to assignable causes, about 10,686 appears to be due to differences between frames. About 87 per cent of this variance, or 9,328, could theoretically be eliminated by employing the load factors shown for Beverly building in Table 6 to balance the traffic loads, and the other 13 per cent might possibly be removed by experimental efforts to bring about a still better balance. But there would still remain a variance of 5,302 per observation due to differences between days, if the three days covered by the study are typical. There is nothing we can do, or desire to do, to eliminate this source of variation. We call a source of this kind an intractable cause, to distinguish it from other assignable causes. The differences between frames are called tractable causes, because we can do something to eliminate them.

While we can not eliminate an intractable cause, we can usually make allowance for it. In the present problem, the easiest way to do this is to compare the load on each frame with the average for all the frames in the central office building. Our objective, then, is to eliminate the tractable causes--that is, the assignable causes of differences between the load on each individual line link frame and the average load for all the frames combined.

COMPUTING CONTROL LIMITS

The problem of balancing, or equalizing, the traffic loads on different line link frames in a central office building is very similar to the problem of keeping a factory process in control. The quality control approach to a problem of this type is (a) to specify a dimension that we want, (b) to compute control limits on either side of this specified dimension on the basis of a statistical analysis of the data, and (c) to take action whenever a dimension (or the average of a specified number of dimensions) falls outside these limits to determine and remove the cause.

In controlling some dimension of a manufactured item, the specified dimension is simply the dimension shown on the blueprint, or the point midway between the outside tolerances shown. By analogy, we might say the average busy-hour traffic load which should be specified as the first step in the application of quality control techniques to balancing line link frames is the maximum load such that the quality of service will barely satisfy accepted engineering requirements. If there were no seasonal variations in the loads, we could actually follow this procedure.

Actually, changes in subscriber line assignments, if necessary, should be made some time in advance of the busy winter season, and the data on which decisions to make such changes are based must be collected for the most part when the loads are below the busy season averages. It would therefore seem desirable to make studies of seasonal variations in the loads by central offices so that busy season loads can be anticipated by projecting the actual loads observed a few weeks or a few months previously. The results of such studies might be used to set up objective average loads for various times of the year that would vary with the normal seasonal pattern. Until studies of this kind have been made, it seems best to estimate the load for each frame from time to time by employing Table 2 and compare each such estimate with the average for all the frames in the central office building. Making such comparisons as the first step in balancing the loads is what our traffic engineers have been trying to do all along, but with less satisfactory data than those now made available.

The new idea that we suggested, as a result of experience with quality control, was to use statistical techniques to establish limits on either side of the average load for use in deciding whether the load on any particular frame was significantly different from the average load; that is, whether an observed difference from the average load should be ascribed to chance or to an assignable cause.

The first step in applying this idea is the usual one of computing the standard deviation in order to measure the variability of the process or operation that is to be controlled. In this case, the data shown in Tables 7 and 8 indicate that the square of the standard deviation due to chance causes in Beverly office building was about 19,310. This is the chance variance of the estimates of the traffic loads for a single frame for one busy hour. The chance variance of the difference between the estimated load on a single frame and the average of all 32 frames would be 31/32 of 19,310, or about 18,707. Taking the square root, we obtain 136.8 as the estimated standard deviation of one of these differences based on one hour's observations. If 32 differences of this kind were computed on the basis of the average traffic loads on 32 frames for J hours, the standard deviation of the chance difference between the average traffic load for a particular frame and the overall average for all 32 frames could be estimated from the formula

$$\sigma_{(x - \bar{x})} = \frac{136.8}{\sqrt{J}} .$$

The result just obtained can be used to compute control limits by employing the equations

$$\text{Upper control limit} = \bar{x} + k\,\sigma_{(x - \bar{x})},$$

$$\text{Lower control limit} = \bar{x} - k\,\sigma_{(x - \bar{x})},$$

where k is a constant that depends on the risks we are willing to take.

In setting control limits, we have to keep in mind that there is always some risk on the one hand that decisions to take action to balance the load will be made when such action is not necessary or even desirable; and some risk on the other hand that no action will be taken when

it ought to be. Unfortunately, reducing one kind of risk increases the other kind. The problem is to find the optimum balance between the two kinds of risks. The solution depends in part on the relative costs associated with the two kinds of wrong decisions. What we want is a decision rule that will minimize the sum of the costs in connection with both kinds of wrong decisions.

In balancing line link frames, the cost of a decision not to take action when a frame is actually overloaded includes the loss of revenue due to calls not completed and the intangible loss of customers' good will when poor service is furnished, together with the excess cost of last minute emergency measures that may have to be taken to get relief when overflows and dial tone delays become too numerous. The cost of a decision not to take action when a frame is actually underloaded includes the possible expense in connection with the adding of new frames and common equipment that could be deferred or dispensed with altogether if existing frames were properly balanced, and the loss in revenue and good will that may result in not furnishing as good service as would be possible in a perfectly balanced office.

The cost of a decision to take action to balance the load when there is no necessity for it depends on the type of action taken. If major changes in the line assignments to the frames are made, the cost will be considerable. If, on the other hand, the action taken consists merely in making line assignments in connection with subscribers' requests for service so that heavy usage lines tend to be assigned to underloaded frames and vice versa, the cost will be relatively small. It was therefore suggested that in the line assignment work from day to day in connection with service orders, some attention be paid to balancing the loads indicated by the most recently available load-to-peg-count ratios, even though the loads for all frames are within the control limits which are recommended. The limits should be used only in deciding when action is necessary to change existing assignments of lines in order to bring about a better balance of the loads.

Since the cost of a wrong decision to change existing assignments when no change is necessary is considerable, the control limits ought to be fixed so that the risk of incorrectly deciding that a change is necessary is small. Where the averages to be controlled tend to vary so that their distribution agrees approximately with the bell-shaped "normal distribution," the usual quality control practice of setting the control limits at 3 standard deviations above and below the specified average makes this risk only about 1 in 370. Since the risk is so small, the rule is followed of taking appropriate action every time an observed average is outside the control limits. On the other hand, the probability of not taking action when the true average differs from the objective average may be rather large, particularly when the difference is small. For large differences that might cause serious trouble, however, the risk of not taking action is usually not too large; and by taking observations at fairly frequent intervals the risk of not taking action when trouble persists over a long period is also fairly small. Control limits set at 3 standard deviations from the objective thus discriminate pretty well between situations where action is needed and situations where it is not. We decided to use 3 standard deviations in setting the control limits.

For Beverly office building, the results discussed earlier indicate

that for one hour's observations, corresponding to $J = 1$, the standard deviation of the traffic load on a particular frame as measured from the average traffic load on all 32 frames is 136.8 ccs units. This is roughly $10\frac{1}{2}$ per cent of the average traffic load of about 1296 ccs units during the 3 days covered by the study underlying Tables 7 and 8. An analysis of estimated traffic loads for 30 frames in Lakeview office building indicated that the standard deviation of these estimates, as measured from the overall average of 1071 ccs units, was about 10 per cent of this average. In both offices, then, it appeared the control limits should be set at about 3 times 10 or 11 per cent, or about 33 per cent, on either side of the average traffic load for the particular office, where the observations covered one hour. Or more generally, where the observations cover J hours, the control limits should be about as follows:

$$\text{Upper control limit} = \bar{X}\left(1 + \frac{1}{3\sqrt{J}}\right),$$

$$\text{Lower control limit} = \bar{X}\left(1 - \frac{1}{3\sqrt{J}}\right).$$

There remained the question of how large to make J; in other words, how many hours should be observed in computing $\bar{X}$. Tests in the two central office buildings selected for study seem to indicate that if we compute the traffic loads on the basis of only one busy hour's observations, and therefore put $J = 1$ in computing control limits, the same frame might be above the upper control limit one busy hour and below the control limit during a busy hour several days later. Hence, if we used these control limits as a basis for taking action to change existing assignments of subscriber lines, we might be in the silly position of trying to decrease the frame load one day and trying to increase it another day.

The anomalous situation where contradictory decisions like these are possible could be due to either or both of two causes: (1) an unusual situation, or "assignable cause," might be present that makes the actual traffic loads for some frames vary from time to time above and below the average load for all frames in the office; (2) the data might vary in such manner, and the estimating procedure might be such, that extreme variations in the estimates tend to occur more frequently than in a normal distribution, even in situations that are not unusual. In either case, combining data for several days might tend to eliminate the difficulty. Investigation indicated that if the traffic load were computed on the basis of 10 busy hours, the difficulty would disappear. In this case, the control limits should be computed by substituting 10 for J in the formulas. The result is roughly equivalent to setting the control limits at 10 per cent on either side of the 10-hour average.

FURTHER SUGGESTIONS

As one of the engineers in the Bell Telephone Laboratories has pointed out, the control limits could be fixed in terms of the ratio of load registrations to terminating peg count, without converting this ratio to ccs units by employing Table 2. Since the relationship between this ratio and the number of ccs units is approximately linear over short intervals, the 10 per cent limits on one basis are very nearly equivalent to the 10 per cent limits on the other basis.

The conversion to ccs units should be made, of course, in computing

the load factors by classes of service on the basis of busy-season busy-hour data. Because of the number of computations involved, it seems desirable to use punch card tabulating equipment to make these computations about once a year, with data for the various offices processed successively. The procedures and results should be reviewed from time to time by a statistician familiar with regression analysis. The possible substitution of these load factors for the ones now computed by engineering analysis is being explored by our traffic administrative people.

In the meantime, the 10 per cent limits based on 10 days' observations are proving useful in determining when to take action to balance the loads. In one operating area, the practicability of measuring loads by groups of 10 links is being studied, with a view to using such measurements in determining which group or groups of links is out of line when a frame of 100 links is outside the control limits.

There is also a possibility that linear programming techniques might be useful in balancing the traffic loads on line link frames and common equipment. There are restrictions on the number of subscriber lines that can be assigned to a particular frame that bear a certain similarity to the restrictions found in many linear programming problems. The techniques ordinarily used in solving these problems might be useful in deciding how to assign the various classes of service when a central office is first converted to dial operation.

There are certain complications, of course. The restrictions to be imposed are a little different from those that lend themselves to the usual solution by the simplex method. Moreover, the traffic loads behave more or less like random variables, instead of the "fixed" variables in the usual linear programming solution. With modern, high-speed computing equipment, however, it should be possible to use the Monte Carlo approach to solve almost any of our programming problems.

To achieve the optimum result, the scope of the problem should be broadened beyond that of just balancing line link frames. We might investigate, for example, whether 10 links or some larger or smaller number of links, is the optimum size of a horizontal group. We might look into the question of the most efficient use of other telephone equipment. There are also many problems involving the optimum use of our manpower.

In trying to solve these problems, we should not confine ourselves to solving the immediate problems that are presented, but try to look at the broad picture. We should bring to bear all the techniques now available to mathematicians, statisticians, engineers, and administrative experts. We should adopt the teamwork principle that is emphasized by people in operations research. Only by doing these things can we accomplish our ultimate objective of furnishing the best telephone service at the least cost consistent with financial safety and the fair treatment of our employees.

APPENDIX

1. Estimates of Traffic Loads for Model No. 1

Let P_k denote the proportion of the time k or more links in an infinite (very large) group of links are busy during a series of observations, and assume that values of P_k for any two observations are statis-

tically independent of each other. Let P'_k denote the value of P_k for an infinitely large number of observations; that is, P'_k is to denote the probability that k or more links are busy at any particular time. Then it is well known that the expected value of P_k is

$$(1.1) \quad EP_k = P'_k,$$

and that the standard deviation of P_k is given by the familiar formula

$$(1.2) \quad \sigma_{P_k} = \sqrt{\frac{P'_k(1 - P'_k)}{n}},$$

where n is the number of observations.

Assume that the probability that exactly x links are busy is the (x + 1)th term in the Poisson distribution,

$$(1.3) \quad p'_x = e^{-a'} \frac{(a')^x}{x!},$$

where a' is the average number of busy links. Then the probability that k or more links will be busy is given by

$$(1.4) \quad P'_k = e^{-a'} \left[\frac{(a')^k}{k!} + \frac{(a')^{k+1}}{(k+1)!} + \frac{(a')^{k+2}}{(k+2)!} + \cdots \right].$$

This probability may also be written in the form

$$(1.5) \quad P'_k = 1 - e^{-a'} \left[1 + a' + \frac{(a')^2}{2!} + \frac{(a')^3}{3!} + \cdots + \frac{(a')^{k-1}}{(k-1)!} \right].$$

Consider the inverse function

$$(1.6) \quad a' = f(P'_k).$$

Let a (without the accent mark) denote an estimate of a', obtained by substituting P_k for P'_k in equation (1.6). Assume that a can be expanded in a Taylor series,

$$(1.7) \quad a = f(P'_k) + hf_1(P'_k) + \frac{h^2}{2!} f_2(P'_k) + \frac{h^3}{3!} f_3(P'_k) + \cdots,$$

where f_1, f_2, f_3, ... denote successive derivatives of $f(P'_k)$ with respect to P'_k, and h is the difference,

$$(1.8) \quad h = P_k - P'_k.$$

Assume further, that in approximating the mean and variance of a, we can neglect terms beyond the first degree in the second order moments of h. We can then write the approximate relationships,

$$(1.9)\quad Ea = f(P'_k) + 1/2\ f_2(P'_k)E(h^2),$$

$$(1.10)\quad \sigma_a^2 = \left[f_1(P'_k)\right]^2 E(h^2),$$

where E denotes expected value, and σ_a^2 is the variance of the estimate a.

From equations (1.8), (1.1), and (1.2),

$$(1.11)\quad E(h^2) = \sigma_{P_k}^2 = \frac{P'_k(1 - P'_k)}{n}.$$

Moreover,

$$(1.12)\quad f_1(P'_k) = \frac{1}{(dP'_k)/(da')}.$$

By differentiating (1.5), we obtain

$$(1.13)\quad \frac{dP'_k}{da'} = P'_{k-1} - P'_k = p'_{k-1} = e^{-a'}\ \frac{(a')^{k-1}}{(k-1)!}$$

where p'_{k-1} is the probability that exactly $(k - 1)$ links are busy. To obtain $f_2(P'_k)$, we write

$$(1.14)\quad f_2(P'_k) = \frac{df_1(P'_k)}{dP'_k} = \frac{df_1(P'_k)/d(a')}{d(P'_k)/d(a')},$$

whence

$$(1.15)\quad f_2(P'_k) = \frac{p'_{k-1} - p'_{k-2}}{(p'_{k-1})^3}.$$

By combining (1.15) with (1.6) and (1.9), we find the bias in a as an estimate of a' to be given approximately by the formula,

$$(1.16)\quad Ea - a' = \frac{1}{2}\ f_2(P'_k)E(h^2)$$

$$= \frac{1}{2}\ \frac{p'_{k-1} - p'_{k-2}}{(p'_{k-1})^3}\ \frac{P'_k(1 - P'_k)}{n}.$$

The variance of a' is given approximately by the relationship,

$$(1.17)\quad \sigma_{a}^{2} = \frac{1}{(p'_{k-1})^2} \frac{P'_k(1 - P'_k)}{n} .$$

We can now determine the range of values of a' for which a specified number, k, is optimum. The general procedures is to find two numbers, a'_1 and a'_2, such that

$$(1.18)\quad \phi(a'_1, k) = \phi(a'_1, k - 1),$$

$$(1.19)\quad \phi(a'_2, k) = \phi(a'_2, k + 1),$$

where ϕ is the function of a' and k that measures the property of the estimates in which we are interested.

Thus, to find the range of values for which $k = 4$ is optimum from the standpoint of the standard deviation of estimates of P'_4, we put

$$(1.20)\quad \phi(a'_1, k) = \sigma_{P_k}^{2} = \frac{P'_k(1 - P'_k)}{n} ,$$

and solve equations

$$(1.21)\quad \frac{P'_4(1 - P'_4)}{n} = \frac{P'_3(1 - P'_3)}{n}$$

and

$$(1.22)\quad \frac{P'_4(1 - P'_4)}{n} = \frac{P'_5(1 - P'_5)}{n}$$

for a'. The solutions are

$$(1.23)\quad a'_1 = 3.16, \qquad a'_2 = 4.16,$$

respectively. Multiplying by 36, we obtain 114 to 149 as the range of ccs units per group of 10 links for which 4 is the optimum value of k with respect to the standard deviation of the sampling errors in P'_k.

Similarly, to find the range of values for which $k = 4$ is optimum from the standpoint of the standard deviation of estimates of a', we put

$$(1.24)\quad \phi(a'_1, k) = \sigma_{a}^{2} = \frac{1}{(p'_{k-1})^2} \frac{P'_k(1 - P'_k)}{n} .$$

Solving equations equivalent to (1.18) and (1.19), we obtain

(1.25) $a'_1 = 2.73, \qquad a'_2 = 3.73.$

Multiplying by 36, we obtain 99 to 134 as the range of ccs units for which the setting $k = 4$ is optimum from the standpoint of minimizing σ_a.

Equation (1.16) indicates that the bias in the estimates of a' is approximately zero if $k = a' + 1$, since $p'_{k-1} = p'_{k-2}$ for this value of k. Thus, there will be little or no bias in estimates of the average number of busy links for $k = 4$ if the actual average is in the neighborhood of 3. The range of values of a' for which the setting $k = 4$ is optimum from the standpoint of the bias in estimates of a' may be regarded as that range for which the numerical value of the bias is less than for any other setting. Hence, we put

(1.26) $\phi(a'_1, k)$ = Numerical value of

$$\frac{1}{2}\left[\frac{p'_{k-1} - p'_{k-2}}{(p'_{k-1})^3}\right]\left[\frac{p'_k(1 - p'_k)}{n}\right] .$$

Solving equations equivalent to (1.18) and (1.19), we obtain

(1.27) $a'_1 = 2.51, \qquad a'_2 = 3.51.$

Multiplying by 36, we obtain 91 to 126 as the range of ccs units for which the setting $k = 4$ is optimum with respect to bias in the estimate of a.

2. Estimates of Traffic Loads for Model No. 2

Assume that telephone calls are generated over subscriber lines in such manner that each call lasts exactly one minute, beginning and ending on the even minute, and such that the probability that a call will be generated over a particular line at any particular minute is

(2.1) $p' = a'/N,$

where N is the number of subscriber lines, assumed to be very large, and a' is an unknown constant. Assume that the probability that a call will be generated over a particular line at a particular minute is independent of the probability that a call will be generated over the same line some other minute, and also independent of the probability that a call will be generated over a different line at the same minute or any other minute. Also, assume that two registers are connected to these lines, which score each minute as follows:

1. A peg count register scores each minute according to the number of calls generated. Thus, if x calls are generated in a particular minute, the peg count register scores x times.

2. A load register that scores each minute according to the number of calls generated in excess of some fixed number k. Thus, if $x \leq k$ for some particular minute, the load register will not score. If $x > k$, the load register scores $x - k$ times.

Let x_i denote the number of calls scored by the peg count register during the ith minute, and y_i denote the number of calls scored by the load register during that same minute. Also, for a period of M consecutive minutes, let

$$(2.2) \quad X = \sum_{i=1}^{M} x_i,$$

$$(2.3) \quad Y = \sum_{i=1}^{M} y_i.$$

The problem is to estimate a' from X and Y, and to investigate the properties of the estimate.

For any particular minute, the probability that exactly x lines will be busy, and x calls will therefore be scored by the peg count register, is

$$(2.4) \quad p_x = \binom{N}{x}(p')^x(1 - p')^{N-x}.$$

For large N and small x, this probability is approximately of the form

$$(2.5) \quad p_x = e^{-a'} \frac{(a')^x}{x!}.$$

By definition

$$(2.6) \quad y = \begin{cases} 0 & \text{if } x \leq k, \\ x - k & \text{if } x > k. \end{cases}$$

Hence, the probability that y calls will be scored by the load register any particular minute is

$$(2.7) \quad p_y = \begin{cases} 1 - P_k & \text{for } y = 0, \\ p_x & \text{for } y = x - k > 0, \end{cases}$$

where

$$(2.8) \quad P_k = 1 - \sum_{x=0}^{k} p_x.$$

Let $\phi(X,Y|k,M)$ denote the joint probability that exactly X calls will be counted by the peg count register and Y calls by the load

register during a period of M minutes. We can then write an explicit expression for $\phi(X,Y|k,M)$ for various values of M. Thus, for the trivial case where M = 1,

$$(2.9)\quad \phi(X,Y|k,1) = \begin{cases} p_X & \text{for } 0 \le X \le k, \quad Y = 0, \\ p_X & \text{for } 0 \le k < X, \quad Y = X - k, \\ 0 & \text{otherwise,} \end{cases}$$

where p_X is obtained by substituting X for x in equation (2.4). For M = 2,

$$(2.10)\quad \phi(X,Y|k,2) = \begin{cases} \binom{2N}{X}(p')^X(1-p')^{2N-X} & \text{for } 0 \le X \le k, \ Y = 0, \\ 2p_0p_X & \text{for } 0 \le k < X, \ Y = X - k, \\ \binom{2N}{X}(p')^X(1-p')^{2N-X} - 2p_0p_X & \text{for } 0 \le 2k < X, \ Y = X - 2k, \\ 0 & \text{otherwise.} \end{cases}$$

Theoretically, we can derive the exact form of the probability function $\phi(X,Y|k,M)$ for $M > 2$; and we might use this function to formulate a maximum likelihood estimate of a', and investigate the properties of such estimates. The derivation and investigation looks like a formidable undertaking, however; and the improvement over the estimates based on Model No. 1 may be negligible. It is conceivable that the estimates might turn out to be worse than these based on Model No. 1, even though Model No. 2 appears more realistic.

To date, no attempt has been made to carry the investigation of Model No. 2 any further.

3. Computation of Load factors and Analysis of Variance of Estimated Traffic Loads on Line Link Frames

This section briefly covers the theory underlying the computation of the load factors representing the average load per line for different classes of service, and the analysis of variance of the estimated traffic loads.

Suppose that each of I frames in a central office building is observed for J hours; and let y_{ij} denote the observed (estimated) traffic loads for the ith frame during the jth hour ($i = 1, 2, \ldots, I$; $j = 1, 2, \ldots, J$), there being IJ observations altogether. Let F_i and H_j denote "dummy variables" such that

$$(3.1)\quad F_i = \begin{cases} 1 & \text{for the ith frame,} \\ 0 & \text{for any other frame,} \end{cases}$$

(3.2) $H_j = \begin{cases} 1 & \text{for the } j\text{th hour,} \\ 0 & \text{for any other hour.} \end{cases}$

Also, let S_{ik} denote the number of subscriber lines of the kth class of service ($k = 1, 2, \ldots, K$) that are served by the ith frame, S_{ik} being the same for every j. Table 9 shows the notation for the illustrative case where $I = 3$, $J = 3$, and $K = 2$.

TABLE 9
ILLISTRATIVE COMBINATION OF VARIABLES
FOR 3 FRAMES OBSERVED FOR 3 HOURS

i	j	F_1	F_2	F_3	H_1	H_2	H_3	S_{i1}	S_{i2}	y_{ij}
1	1	1	0	0	1	0	0	S_{11}	S_{12}	y_{11}
1	2	1	0	0	0	1	0	S_{11}	S_{12}	y_{12}
1	3	1	0	0	0	0	1	S_{11}	S_{12}	y_{13}
2	1	0	1	0	1	0	0	S_{21}	S_{22}	y_{21}
2	2	0	1	0	0	1	0	S_{21}	S_{22}	y_{22}
2	3	0	1	0	0	0	1	S_{21}	S_{22}	y_{23}
3	1	0	0	1	1	0	0	S_{31}	S_{32}	y_{31}
3	2	0	0	1	0	1	0	S_{31}	S_{32}	y_{32}
3	3	0	0	1	0	0	1	S_{31}	S_{32}	y_{33}

Consider the estimating function

$$(3.3)\quad \phi(F_i, H_j, S_{ik}) = f_i F_i + h_j H_j + \sum_{k=1}^{K} b_k S_{ik},$$

where f_i, h_j, and b_k are unknown parameters. The problem is to find the least squares estimates of f_i, h_j, and b_k; that is, the estimates that minimize the function

$$(3.4)\quad z = \sum_{i=1}^{I} \sum_{j=1}^{J} (f_i F_i + h_j H_j + \sum_{k=1}^{K} b_k S_{ik} - y_{ij})^2.$$

Suppose we proceed in straight-forward fashion, and set the partial derivative of z with respect to each f_i, h_j, and b_k equal to zero. We shall then obtain equations of the following forms:

$$(3.5)\quad \partial z/\partial f_i = 2\sum_{j=1}^{J} F_i(f_iF_i + h_jH_j + \sum_{k=1}^{K} b_kS_{ik} - y_{ij}) = 0,$$

$$i = 1, 2, \ldots, I,$$

$$(3.6)\quad \partial z/\partial k_j = 2\sum_{i=1}^{I} H_j(f_iF_i + h_jH_j + \sum_{k=1}^{K} b_iS_{ik} - y_{ij}) = 0,$$

$$j = 1, 2, \ldots, J,$$

$$(3.7)\quad \partial z/\partial b_k = 2\sum_{i=1}^{I}\sum_{j=1}^{J} S_{ik}(f_iF_i + h_jH_j + \sum_{k=1}^{K} b_kS_{ik} - y_{ij}) = 0,$$

$$k = 1, 2, \ldots, K.$$

It turns out that these equations are not independent. In particular, summing equations (3.5) for i = 1, 2, ..., I yields the same result as summing equations (3.6) for j = 1, 2, ..., J. Moreover, multiplying each equation (3.5) by S_{ik}, for fixed k and i = 1, 2, ..., I, yields the corresponding equation (3.7).

To illustrate, for the combination of variables shown in Table 9, the "normal equations" corresponding to (3.5), (3.6), and (3.7), after transposing the y's and dividing through by 2, are as follows:

$$(3.8)\quad 3f_1 + h_1 + h_2 + h_3 + 3S_{11}b_1 + 3S_{12}b_2 = y_{11} + y_{12} + y_{13},$$

$$(3.9)\quad 3f_2 + h_1 + h_2 + h_3 + 3S_{21}b_1 + 3S_{22}b_2 = y_{21} + y_{22} + y_{23},$$

$$(3.10)\quad 3f_3 + h_1 + h_2 + h_3 + 3S_{21}b_1 + 3S_{32}b_2 = y_{31} + y_{32} + y_{33},$$

$$(3.11)\quad f_1 + f_2 + f_3 + 3h_1 + (S_{11} + S_{21} + S_{31})b_1 + (S_{12} + S_{22} + S_{32})b_2 = y_{11} + y_{21} + y_{31},$$

$$(3.12)\quad f_1 + f_2 + f_3 + 3h_2 + (S_{11} + S_{21} + S_{31})b_1 + (S_{12} + S_{22} + S_{32})b_2 = y_{12} + y_{22} + y_{32},$$

$$(3.13)\quad f_1 + f_2 + f_3 + 3h_3 + (S_{11} + S_{21} + S_{31})b_1 + (S_{12} + S_{22} + S_{32})b_2 = y_{13} + y_{23} + y_{33},$$

$$(3.14)\quad 3S_{11}f_1 + 3S_{21}f_2 + 3S_{31}f_3 + (S_{11} + S_{21} + S_{31})(h_1 + h_2 + h_3) + 3(S_{11}^2 + S_{21}^2 + S_{31}^2)b_1 + (S_{11}S_{12} + S_{21}S_{22} + S_{31}S_{32})b_2 = S_{11}(y_{11} + y_{12} + y_{13}) + S_{21}(y_{21} + y_{22} + y_{23}) + S_{31}(y_{31} + y_{32} + y_{33}),$$

$$(3.15)\quad 3S_{12}f_1 + 3S_{22}f_2 + 3S_{32}f_3 + (S_{12} + S_{22} + S_{32})(h_1 + h_2 + h_3) + 3(S_{11}S_{12} + S_{21}S_{22} + S_{31}S_{32})b_1 + S_{12}^2 + S_{22}^2 + S_{32}^2)b_2 = S_{12}(y_{11} + y_{12} + y_{13}) + S_{22}(y_{21} + y_{22} + y_{23}) + S_{32}(y_{31} + y_{32} + y_{33}).$$

It can easily be seen that the sum of equations (3.8), (3.9), and (3.10) is equal to the sum of equations (3.11), (3.12), and (3.13); that equation (3.14) can be obtained by multiplying equations (3.8), (3.9), and (3.10) by S_{11}, S_{21}, and S_{31}, respectively, and adding; and that equation (3.15) can be obtained by multiplying equations (3.8), (3.9), and (3.10) by S_{21}, S_{22}, and S_{32}, respectively, and adding. Thus, all 8 equations could be derived from the first 5. It can be shown that these 5 equations are independent, except in special situations.

In general, there are $I + J - 1$ independent equations. Since there are $I + J + K$ unknown paramters, altogether, we can impose $K + 1$ conditions on the solution without increasing the right-hand side of equation (3.4). For convenience, the conditions may be prescribed as follows:

$$(3.16)\quad \sum_{i=1}^{I}\sum_{j=1}^{J} S_{ik}\left(\sum_{k=1}^{K} b_k S_{ik} - y_{ij}\right) = 0, \qquad k = 1, 2, \ldots, K,$$

$$(3.17)\quad \sum_{j=1}^{J} h_j = 0.$$

Equations (3.16) are the usual "normal equations" for minimizing the function

$$(3.18)\quad Z = \sum_{i=1}^{I}\sum_{j=1}^{J}\left(\sum_{k=1}^{K} b_k S_{ik} - y_{ij}\right)^2$$

with respect to each b_k. These parameters can therefore be estimated in the usual way without considering the parameters f_i and h_j. Substituting these estimates in equations (3.5), and employing (3.17), we obtain I equations of the form

$$(3.19)\quad Jf_i = \sum_{j=1}^{J} y_{ij} - J\sum_{k=1}^{K} b_k S_{ik},$$

each of which can readily be solved for f_i. Then, by substituting the estimated values of f_i and b_k in equations (3.6), we obtain J equations of the form

$$(3.20)\quad Ih_j = \sum_{i=1}^{I} y_{ij} - \sum_{k=1}^{K}\sum_{i=1}^{I} b_k S_{ik},$$

each of which can readily be solved for h_j.

The resulting estimates of the paramters are thus equivalent to those obtained by solving I + J + K equations, subject to K + 1 conditions which in this case do not increase the sum of squares of the residual ("unexplained") differences, but merely make the solution unique. The exact number of degrees of freedom associated with this sum of squares is

$$(3.21)\quad \text{D.F.} = IJ - (I + J + K) + (K + 1)$$
$$= IJ - I - J + 1,$$

and is thus independent of K (the number of load factors, b_k).

Variance estimates as in the usual analysis of variance, can be obtained by dividing the residual sum of squares, after removing the effect of any combination of computed parameters, by the related number of degrees of freedom. The variance assigned to the variable associated with a particular parameter, however, will depend in this particular problem on the order in which the "effects" are computed.

Keeping this caution in mind, we can compute successive sums of squares of residuals in steps, as follows:

A. Compute the value of

$$(3.22)\quad \sum_{i=1}^{I}\sum_{j=1}^{J}(y_{ij} - \bar{y})^2 = \sum_{i=1}^{I}\sum_{j=1}^{J} y_{ij}^2 - \frac{1}{IJ}\left(\sum_{i=1}^{I}\sum_{j=1}^{J} y_{ij}\right)^2 .$$

where

$$(3.23)\quad \bar{y} = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J} y_{ij}}{IJ} .$$

There will be (IJ - 1) degrees of freedom associated with the resulting sum of squares.

B. Compute the parameters $b_1, b_2, \ldots, b_K$ by solving equations (3.16). Use the solution to compute IJ differences of the form

$$(3.24)\quad d_{ij} = \sum_{k=1}^{K} b_k S_{ik} - y_{ij}, \qquad i = 1, \ldots, I;\ j = 1, \ldots, J.$$

The sum of these differences should be fairly small, but will generally not be equal to zero. Compute the sum of the squares of these differences. There will be IJ - K degrees of freedom associated with this sum of squares.

C. Subtract (3.24) from (3.22). There will be (K - 1) degrees of freedom associated with this sum of squares, which affords a measure of the effect of the average traffic loads by classes of service. It is not independent of the other sums of squares, however (it is not even necessarily positive), and should therefore not be employed in testing hypotheses in the usual manner by entering a table of the F - distribution.

D. Compute the sum of squares obtained from

$$(3.25)\quad \frac{1}{J} \sum_{i=1}^{I} d_i^2$$

where

$$(3.26)\quad d_i = \sum_{j=1}^{J} d_{ij}.$$

There will be (I - K) degrees of freedom associated with this sum of squares. It measures the effect of differences between frames not explained by differences in the number of lines by classes of service.

E. Subtract (3.25) from the sum of square obtained in step B. The remainder will be identical to the sum of squares that would be obtained by computing $f_1, f_2, \ldots, f_I$ from equation (3.19), and then using these parameter values to compute

$$(3.27)\quad \sum_{i=1}^{I} \sum_{j=1}^{J} (f_i + \sum_{k=1}^{K} b_k S_{ik} - y_{ij})^2.$$

There will be (IJ - I) degrees of freedom associated with this sum of squares.

F. Compute the sum of squares obtained from

$$(3.28)\quad \frac{1}{I} \sum_{j=1}^{J} d_j^2 - \frac{1}{IJ} \left(\sum_{j=1}^{J} d_j \right)^2 ,$$

where

$$(3.29)\quad d_j = \sum_{i=1}^{I} d_{ij}.$$

There will be (J - 1) degrees of freedom associated with this sum of squares. It measures the effect of differences between days.

G. Subtract (3.28) from the sum of squares obtained in step E. The remainder will be identical to the sum of squares that would be obtained by computing h_1, h_2, ..., h_J from equations (3.20), and then using these parameter values, together with those previously obtained for b_1, b_2, ..., b_k, and f_1, f_2, ..., f_I, to compute the sum of squares indicated by equation (3.4). There will be (IJ - I - J + 1) degrees of freedom associated with this remainder, as indicated in equation (3.21).

4. Illustrative Procedure for the Analysis of Variance of Traffic Loads for Beverly office building.

The computations discussed in Section 3 of this appendix may be illustrated by those made for Beverly office building for May 8, 13, and 22, 1954.

A. Using the estimates of traffic loads each day for each of 32 frames in that office, we first computed the average traffic load per frame by summing the 96 estimates and dividing by 96. Subtracting each estimate from the overall average, squaring each difference, and adding the squares, we obtained 3,369,265 as the total sum of squares.

B. We next estimated the traffic loads by employing the factors shown in Table 6 under "Regression Analysis." These estimates were the same for each of the three days, since the number of subscriber lines remained unchanged, or nearly so. The differences between these estimates and the corresponding estimates based on Table 2 were computed. The sum of the squares of these differences turned out to be 2,415,852.

C. Subtracting 2,415,852 from 3,369,265 leaves 953,413 as the sum of squares attributed to differences between frames in the number of subscriber lines of the various classes of service.

D. Computing the 3-day totals of the differences frame by frame, adding the squares of the differences, and dividing by 3, we obtain 671,030 as the portion of the total variance ascribable to differences between frames, over and above the expected differences due to variations in the number of subscriber lines of the various classes.

E. Subtracting 671,030 from 2,415,852 leaves 1,744,822 as the sum of squares not explained by differences between frames.

F. Summing the 32 differences obtained in step B for each of the 3 days, squaring the difference between each of the 3 sums and their average, and dividing the sum of the squares by 32, we obtain 547,595 as the portion of the total variance ascribable to differences between days.

G. Subtracting 547,595 from 1,744,822 leaves 1,197,227 as the "unexplained variance."

The foregoing steps are the same as those outlined in Section 3 of

this appendix.

The extent to which an analysis of this kind is to be carried will depend on the data available and the uses to which the analysis is to be put. Thus, if the necessary data were available, the "unexplained" variance at step G might be further analyzed to determine the effect of differences between horizontal groups of 10 links, differences between subscriber lines served by each group, differences between days of the week, differences between seasons of the year, and possibly other differences in addition to those that appear to be more or less random. In Chicago crossbar offices, it appears impractical to remove the causes of these differences, or to make allowances for them in balancing the traffic loads on the frames in these offices. For that reason, it seems better not to try to eliminate the effects of these differences in computations of the control limits for these loads. In central offices outside Chicago, the situation may be different. There it may not be practical to eliminate differences due to the number of subscriber lines of the various classes. On the other hand, consideration is being given to the possibility of eliminating differences between groups of 10 links within a frame. The analysis of variance should take into account the conditions as they actually exist.

SAMPLING APPLIED TO ACCOUNTING PROBLEMS*

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Probability sampling in accounting

The purpose of this paper is to show that probability sampling has been applied successfully to several important accounting problems. We shall cite and describe briefly some significant applications which have already appeared in the literature; the justification for describing them here is not only that they are outstanding papers but that they are scattered rather widely in the literature and hence are not readily accessible. We shall also describe in some detail an actual application of random time sampling of activity, or work sampling, to the problem of cost analysis in a government agency.

These applications of probability sampling to accounting problems are not to be interpreted as constituting the limit to which sampling can be carried, but rather as illustrations of the wide variety of problems to which probability sampling has already been applied, or can be applied.

The application of probability sampling to accounting problems follows a pattern similar to that found in many other fields. Accountants, like other professional persons, have occasions when they have to use estimates and inferences derived from samples of observations, records, or transactions. On these occasions probability statistics may be helpful since it is the science which deals with sampling, estimation and inference. Furthermore, accountants, especially cost accountants, may have to use engineering data derived from tests and experiments, and it is necessary for the accountant to know whether these data have been obtained from properly designed samples, tests, and experiments.

Contrary to popular opinion many of the most important figures used in accounting are estimates rather than complete and perfect counts or enumerations. We quote to this effect from an official publication of the American Institute of Accountants (1)

> "Actually the values of most items in financial statements cannot be measured exactly. By their nature, many of the amounts shown have to be approximations and represent the best estimates which those responsible for the statements can make. The items which, in part at least, are subject to approximation are among the most important in the financial statements."

Hence these values are subject to error. This suggests that the data may be derived by applying statistical techniques including sampling.

The six specific applications of probability sampling to be described are the following:

1. Sampling to estimate the condition of physical assets
2. Sampling to estimate an inventory
3. Sampling to settle inter-company accounts
4. Sampling for aging accounts receivable
5. Sampling to verify computations in an accounting department
6. Work sampling as a basis for cost analysis

Sampling to estimate the condition of physical assets

Magruder (2) has described in detail how a large telephone company applied probability sampling to obtain estimates of the composition and condition of its physical assets. How this was done is illustrated by the sampling of the aerial cable account.

A sample of pole locations was selected at random using the pole-line record of some 300,000 poles. Ten random sub-samples were selected so that sampling errors could be computed directly. Sample poles were assigned to inspectors who determined the physical condition of specific items, such as wire, on the basis of a five step condition rating system. Actually numerical values (percentages) were assigned to each grade so that the value of the property could be adjusted for physical deterioration.

This and related applications of sampling are highly important to the company because the results are used in connection with hearings on telephone rates before State rate commissions.

Magruder found that a carefully planned sample actually was more satisfactory than a complete 100 percent enumeration. This situation also reported by statisticians in other fields, is due to the additional care and control which can be exerted over the sample as compared with a complete enumeration. As a result biased error in the sample data is kept at a minimum.

Sampling to estimate an inventory

Rowles (3) has described how probability sampling can be used by a company engaged in manufacturing to estimate the value of its inventory. The inventory size was substantial and highly diverse consisting of 250,000 items in 100 different locations (sales branches). There were over 30 product classes, the largest class containing about 3,500 items.

The sampling frame consisted of listed items within product classes. Stratified random sampling and ratio estimation were used. The precision of the estimate of inventory value at base year costs was set at 1 percent at the 95 percent level. The test sample consisted of 25 percent of the items but this was later reduced to 4 percent.

The following estimates were obtained. The estimate of current cost derived from the sample was $17,567,000 with a sampling error of 0.96 percent at the 95 percent level. The estimate of base year cost from the sample was $11,072,000 with a sampling error of 0.98 percent at the 95 percent level. The ratio or index of current to base valuation was $\frac{17,567,000}{11,072,000} = 158.66$ percent with a sampling error of 0.25 percent at the 95 percent level. An improved estimate of the base year cost was derived by dividing the actual inventory by this ratio:

$$\frac{17,672,000}{158.66} = \$11,138,000$$

This latter estimate has a sampling error of only 0.25 percent at the 95 percent level. This estimate obviously cannot be made unless there is an actual rather than an estimated inventory value.

This example shows how a company, by using its own data, can obtain estimates with known precision, making such estimates preferable to those based on national indexes derived from different prices, different mixes, and with unknown sources of bias.

Sampling to settle intercompany accounts

Dalleck (4) has described how intercompany accounts for airline travel can be settled by a particular airline on the basis of probability sampling. This is a significant application since the portions of a ticket fare due to other airlines are settled, not by processing every ticket, but by processing a designed probability sample of them. A steady increase during recent years in the volume of such tickets has raised the possibility of using sampling. This sampling approach is even more significant because it means a sharp break with regular accounting methods.

Dalleck cites some tests wherein two 5 percent samples gave estimates, one within 0.10 percent and the other within 1 percent, of the true value. Dalleck points out that sampling would be acceptable to the airlines providing the sampling error did not exceed the cost of pricing all of the tickets. Apparently this criterion can be met by proper sample design -- by using efficient methods of stratification and estimation.

If probability sampling is used over a period of time, to settle these accounts, the sampling errors in the various money amounts will tend to approach zero. This is one of the important and desirable characteristics of random sampling.

In a more recent paper (1956) Dalleck uses the term "inductive accounting" to refer to the procedure in which sample data are used in place of the usual accounting values. He reports that three major airlines, as a result of tests extending over two years, are installing the use of sampling to settle intercompany accounts beginning February 1, 1956.

There are other areas of application, such as the railroads and steamship lines, where this technique is also applicable. Obviously it will be much more feasible where there is a very large volume of tickets or bills which have to be settled.

Sampling to age accounts receivable

Trueblood and Cyert (5) describe how sampling can be used in the aging of accounts receivable in a large department store. Aging allows the company to estimate an allowance for uncollectible accounts as well as to obtain other pertinent information about credit practices.

The population consisted of 100,000 accounts receivable cards. These accounts were not numbered so random numbers could not be used. However, the accounts were selected at random by drawing trays of cards at random and then selecting every 10th account in each tray. Two strata by size were used; all accounts in excess of $2500 were selected 100 percent.

The company had been using a sample of 15,000 accounts but this was reduced to 1700 on the basis of a designed probability sample. For this

latter sample the precision was $3000 at the 95 percent level. This precision constituted about a 2 percent variation in an estimated allowance of $143,000.

The company had also hired an auditor to check this aging procedure. He test checked a 10 percent sample of aged accounts, or 1500 accounts. A satisfactory sequential sampling plan was substituted which would require on the average, a sample of only 126 accounts in order to reach a decision as to the satisfactory quality of the work (For the sequential sample $p_1 = .03$, $\alpha = .10$, $p_2 = .08$, and $\beta = .05$).

This example illustrates how a designed probability sample can lead to substantial savings but at the same time produce the quality of data and decisions which are required. In this case the company and the auditor were using excessively large samples for the job that needed to be done.

Sampling to verify computations in an accounting department

Halbert (6) has described how probability sampling can be used to verify clerical work in an accounting department. This clerical work included posting of data from work reports (for cost accounting) and toll ticket rating work (for revenue accounting).

Sampling inspection plans were used but especially the sequential sampling technique. In one plan p_1 was 0.003, p_2 was 0.005, α was .05 and β was .02. In a second sequential plan $p_1 = .0025$, $p_2 = .0075$, $\alpha = .05$, and $\beta = .01$. This plan led to successive samples of 230 tickets each, with the expected average sample size required for a decision exceeding 900 tickets.

These specifications are quite severe and hence account for the large sample sizes required for arriving at a decision of acceptance or rejection.

Sampling was applied to outgoing bills, incoming bills, and operating records. Halbert lists the following conditions as favorable for sampling: substantial volume, comparable work, work units can be classified as correct or incorrect, and complete verification is not feasible.

Before probability sampling was applied 5, 10, and even 15 percent inspection was used. In one case only a 1 percent sample was needed to give the desired protection. (Actually the effectiveness of a probability sample depends on its absolute, not relative size.)

Work sampling as a basis for cost analysis

Work sampling. - The present technique of work sampling, also known as the ratio-delay method, seems to have had its origin in 1935 with Tippett, an English statistician, who applied it to the machinery operators in a textile mill in order to determine the amount of idle time. As applied by Tippett and by modern industrial engineers, work sampling refers to the use of random time sampling for the purpose of estimating the frequency of occurrence (proportion or percentage) of specified work and non-work activities in a factory or in an office. Papers and discussions on work sampling usually end here; they do not indicate how the work sampling data are used for purposes of cost analysis, cost control, budget planning, or other accounting purposes.

Cost analysis techniques. - There are many techniques which can be used to estimate the labor or salary cost of an activity, a job, a project, or a product.

In one method each employee fills out a data record showing each activity or job engaged in during the day, and how much time was spent on each. This method is time consuming, expensive, often inaccurate, and does not give a representative picture of what the person does if it is limited to a short period of time and the activities or projects vary to any extent over time.

Another method is the ticket system designed to determine how much a job or product costs. In this case the project must usually be completed before any information is available. Furthermore, if several projects move by various routes simultaneously through the factory or office, the system becomes complicated.

A third method is to make a test run. Often the practice here is to select a few persons, often only one, and make a test run on a machine or non-machine operation. From such a run estimates are made of the time required to make a unit of product. Such test runs may lead to highly misleading results because the sample may be biased as well as too small. The solution is to use a designed test or experiment so unbiased estimates can be obtained and so that probability statistics can be applied to interpret the data.

Finally there is the method of work sampling, or ratio delay as it is sometimes called, based on the selection of random times for observing the activity of a worker. This technique has many advantages. It is simple and inexpensive yet if properly designed it can give very reliable estimates. Furthermore, it is feasible from an administrative point of view requiring very little time from workers and management. (However, careful technical and administrative planning and direction is necessary if this goal is to be achieved.) Work sampling allows estimates of time and costs by types of projects and jobs to be made immediately; costly operations are spotted at once from the sample data. By using random time sampling, bias due to sampling is eliminated, and a representative pattern of activity is assured.

An application to cost analysis. - We wish to describe how work sampling is being applied in the Statistics Division of the Internal Revenue Service for the purpose of cost analysis and budget planning. The Statistics Division has a total of about 350 employees including Administrators, professional personnel, supervisors, machine operators, and clerks. In the Internal Revenue Service organization the Division is under the Assistant Commissioner (Planning). The Division consists of a Planning Branch and an Operating Branch, which together consist of a total of 24 sections and offices.

The application of work sampling in the Statistics Division was initiated in order to provide management with time and cost data which could be used for planning and budget purposes. For example, management wanted to know what proportions of time and of salaries were being spent on major activities, and what proportions were being used for special jobs requested by personnel not in the Division.

This application has several features not usually found in the current practice of work sampling:

1. All 350 persons, from the messengers to the Director, are included in the sample.

2. Data records are anonymous and filled out by each individual, or supervisor if the individual is absent.

3. The estimation of costs is part of the sample design.

4. The sample is an activity sample, not just a delay or work sample.

5. Random times include any of the 480 minutes during the working day.

These are departures from current practice because rarely is work sampling applied to an entire unit in an organization. Usually data are recorded by independent observers. The estimation of cost is seldom if ever a part of the sample design. Furthermore, many work samples apply only to delay or work activities, but not to non-work activities as well. Finally, it is not unusual to eliminate some of the working day from the random time sample (For example see Abruzzi, Work Measurement, Columbia University Press).

The design of a work sample. - Some of the technical problems involved in designing a work sample can be defined by referring to an activity matrix, a two-way table with M time units across the top, and N persons along the side, with some activity A_{11}, A_{12}, A_{13}, etc. being associated with each of the M N cells. Every problem in work sampling involves an activity matrix.

The Activity Matrix

	Time Units						
Individual	1	2	3	-	j	-	M
1	A_{11}	A_{12}	A_{13}		A_{1j}		A_{1M}
2	A_{21}	A_{22}	A_{23}		A_{2j}		A_{2M}
3	A_{31}	A_{32}	A_{33}		A_{3j}		A_{3M}
. . .							
i	A_{i1}	A_{i2}	A_{i3}		A_{ij}		A_{iM}
. . .							
N	A_{N1}	A_{N2}	A_{N3}		A_{Nj}		A_{NM}

The A's may be identical and exist in clusters, by both rows and columns depending upon what each individual is doing during the M time units, and depending upon whether or not the N individuals are engaged in the same activity, or in different activities. The time units may be half-minutes, minutes, five minute intervals, etc. For the activity matrix to be valid it is necessary for the time units to be small enough so as to be identified with one activity. However, a change from one activity to another may take place within a time unit. If the number of these changes is very small compared with 480 minutes, then the effect of these changes can be ignored. If not then a smaller time unit can be used.

One way to interpret the activity matrix is as follows. When we select a minute at random during the working day and determine what a person is doing at that instant, we can assume that the person was engaged in this activity during the entire minute preceding the instant selected. This will be a sound assumption for situations where persons are engaged in specific activities whose duration will greatly exceed one minute. This is the case in the application we are describing.

Another way of interpreting the activity matrix is to assume that the various types of activities for which we design estimates of time and cost are distributed over 480 instants of time in the same way that they are distributed during the 480 minutes. If the various types of activities are independent of specified minutes then this will tend to be the case. The principle will not hold if any activity is limited to time durations within minutes. This latter condition however would seem to be very rare indeed.

Certain factors have to be taken into consideration in the design of a work sample:

1. Do we sample only time units, or both time and personnel?

2. How rare a characteristic do we try to estimate?

3. Do we use unrestricted random sampling, or stratified random sampling?

4. How do we allocate the total sample to time and to strata?

Whether we sample both time and personnel depends largely upon the pattern of activity of the personnel. If it is much the same for each individual, then a sample of persons, as well as a sample of time, can be used. Often we may wish to include all persons rather than to sample them because of the administrative difficulties often encountered in trying to sample individuals at work in a factory or office.

When we use a random time to obtain work data from everyone in a group, or in a series of groups of unequal size, we have a cluster sample, and the sampling error associated with such a sample.

Three other questions involving time are also significant. The first question is "How do we select random times such as minutes?" One effective way is to use a table of random numbers employing three or four digits. If a work day is from 8:00 to 12:00 and from 1:00 to 5:00 pm, then all random numbers from 0801 through 1200, and from 101 through 500 can be used, the random number having the same digits as the digits

in the time.

A second question is "How large a time interval should be used?" If a small time unit such as a minute is used, it is not likely that the activity engaged in will change during that time. Hence a minute is likely to give good estimates of the percentage of time engaged in a given activity. On the other hand if too broad a time unit is used then several types of activity may be engaged in and a poor estimate of a specified activity may be obtained.

A third question is "How effective is cluster sampling?" Cluster sampling, that is the sampling of time without the sampling of groups of individuals, can be very effective, if there is a wide variation in the activities of the various persons of the group. In fact under this condition, cluster sampling may be better than unrestricted random sampling. Cluster sampling is inefficient however where there is a great deal of homogeneity in the activities of the persons of the group. In such a case the sampling of only a few individuals may give a very good estimate of the activity pattern of the entire group.

Rare characteristics, such as an activity that accounts for less than 5 percent of a person's time, require large samples in order to obtain adequate estimates of their occurrence. Furthermore, these samples may be so large as to be unfeasible from the viewpoint of management, or they may require the accumulation of sample records over a period of several months.

It is difficult to avoid stratification in work sampling since time such as days, weeks, or months, may be strata; furthermore, different groups of workers may differ in their work patterns enough to constitute natural strata.

How the total sample is allocated to time, to persons, and to strata depends upon how variable and rare is the characteristic to be estimated, as well as how feasible it is to sample persons.

A test run. - We turn now to a description of the details of the application mentioned above. A test run was made during the first week of June 1955 to determine the technical and administrative feasibility of a work sample.

Eight random time samples were taken of the work of each person each day for five days. The time unit of random selection was the minute. When each random time was called, for any section or office, every person filled out a data record giving the type of activity, and the identification number of the project engaged in. Also checked were the date, the time, the salary grade, and the organizational unit. The record was made anonymous since data on each individual were not required, and it was hoped anonymity would improve reporting. The sample was administered through 24 organizational units and offices into which the Division is divided, and in general no two of these units or offices were sampled at the same time. Five persons were used to inform units of the random times and to collect data records.

As a result of this test it was shown that a work sample was feasible both technically and administratively. Analysis of the variability of major characteristics within and between days by means of chi-square tests showed that 8 samples per day per person were not

necessary; actually only one sample per day was necessary. Indeed variability between adjacent days seemed to indicate that samples every day were not required. These findings are valid over short periods of time providing estimates are limited to values of time and costs allocated to broad types of activity, to major projects, and to organizational units. They are valid also providing estimates for fairly rare characteristics can be made from a work sample accumulated over a number of months.

As an example of a chi-square test consider the following data for activity A. The entries are frequencies with which this activity was checked in the morning and in the afternoon in four organizational units. The chi-square test shows that there is no significant difference between the frequency of occurrence in the morning and in the afternoon. If there is enough of this type of evidence it means that it is unnecessary to sample both morning and afternoon for this activity.

Frequency of occurrence of activity A

Organizational Unit	A.M.	P.M.	Total
1	74	87	161
2	51	56	107
3	22	22	44
4	11	21	32
Total	158	186	344
Work time division	50	50	100%
Expected frequency	172	172	344

$$x^2 = \frac{14^2}{172} + \frac{14^2}{172} = 2.28$$

For one degree of freedom the test is not significant. Neither is it significant when the test is applied to each of the organizational units.

While the technical aspects of the sample design were important the management of the sample and the reporting of the data were just as important. In order to control nonsampling sources of bias it was necessary to instruct every employee relative to the identification and classification of activities. This was done for the test run by instructing the employees in small groups relative to the sampling method and the data recording procedure to be followed. Activities not only had to be classified by broad types but they had to be identified with specifically numbered projects when a random time was called. A list of such projects by number designation was furnished to each supervisor so that every employee could be properly informed as to the project he was working on, preferably before any random times were called. Data sheets for anyone absent from his desk were filled out by the supervisor or by the secretary for that office.

As a result of the test run we discovered that even more careful instruction of employees and supervisors was called for. Consequently a booklet of instructions was prepared for employees describing in more detail various procedures and listing code numbers to be applied to activities not covered by the project list. We found it necessary also to ask every supervisor to review the data sheets for his unit to insure that (1) one data sheet was obtained for every person for every time called, and (2) that each sheet contained no gross errors such as wrong salary grade, organizational unit, or broad type of activity.

The current sample. - As a result of the test run a work sample was designed which could be carried out continously by the administrative office of the Division within its limited resources.

All persons are still included in the work sample. This sample means a much simpler procedure than trying to sample individuals (as well as time) even though technically the sampling of individuals in some units would be justified.

Three random time samples of work are selected per week for each person in the Program Branch, and two random time samples of work are selected per week for each person in the Operations Branch. A larger sample is required in the former group because of the greater variability of the activities. The time unit used as the basis of random selection is the minute; each day consists of 480 minutes so any one of these minutes can be selected in the random sample for any day. Only one random time sample is selected during any one day for any person.

Various units are informed by telephone of each random time for which a data record is required. This telephoning requires only part of a day of the time of one person. Anonymous self reporting is used plus a review of each data record by the supervisor or secretary.

This sample results in about 3,000 punch cards per month which is a feasible data-processing load. A punch card is punched for each person for each random time, and is used as the basis for a tabulation which is submitted each month to the Director.

Another feature of this work sample is that it has been applied continuously over a period of several months. This fact has made it possible to obtain information on the extent and size of the month to month variations in the various types of activities for which we make estimates.

A continuous work sample has another advantage. When it becomes routine then persons tend to follow natural patterns of work behavior. On the other hand in a very short run, the very fact that work sample is being selected may influence a person's behavior.

The study has proven its worth by supplying management with valuable time and cost data relative to (1) various projects, (2) various customers requesting our services, (3) various sections and offices within the Division, and (4) various types of activities.

The estimation of time spent on an activity. - The activity matrix consisting of M N, cells each identified with some activity A_{ij}, leads directly to the estimation of the proportion of time spent by each cluster (column) of persons, by a group of clusters, or by all N persons.

Let $Y_{ij} = 1$ if activity A_{ij} is under study and zero otherwise. Then the proportion of time spent on activity A_{ij} in the jth cluster (time period) is

$$P_j = \frac{1}{N} \sum_{1}^{N} Y_{ij}$$

Furthermore the population proportion of time spent on a particular activity A over the total period of time is as follows:

$$P = \frac{1}{M} \sum_{1}^{M} P_j$$

If a random sample of m clusters (time periods) is selected from the total of M clusters (time periods) then an unbiased estimate of P is as follows:

$$p = \frac{1}{m} \sum_{1}^{m} P_j$$

We can illustrate these formula by means of the following simple table where 1 designates the activity in question and 0 its absence.

	M				
N	1	2	3	4	5
1	0	0	1	1	1
2	0	0	0	0	0
3	1	1	1	1	1
4	0	0	0	0	0
Y_j	1	1	2	2	2
P_j	1/4	1/4	1/2	1/2	1/2

$P_1 = 1/4 \times 1 = 1/4$, $P_2 = 1/4 \times 1 = 1/4$, etc.

$P = 1/5\ (1/4 + 1/4 + 1/2 + 1/2 + 1/2) = .40$

Also $P = \frac{\Sigma\Sigma Y_{ij}}{MN} = \frac{8}{20} = .40$

Assume that the second and fourth time intervals are selected in the sample so that m = 2. Then an estimate of the population value P = .40 derived from the random sample is

$p = 1/2\ (1/4 + 1/2) = .375$

The estimation of the cost of an activity. - A logical counterpart of the activity (A) matrix is the unit cost (C) matrix shown below. In this matrix there are M N cells the same as in the activity matrix, but each cell entry in a row is the salary cost C of a particular person for the time unit used. For example if

$$M = 2 \text{ weeks} = 480 \times 5 \times 2 = 4800 \text{ minutes}$$

and if a weekly salary is $60 then

$$C = \frac{60 \times 2}{4800} = \frac{120}{4800} = \$.025$$

These values are constant for each row so long as the salary does not change, but may vary from row to row to the extent to which the salaries of individuals differ.

The Unit Cost Matrix

Persons	Time Units 1	2	3	j	M
1	C_{11}	C_{12}	C_{13}	C_{1j}	C_{1M}
2	C_{21}	C_{22}	C_{23}	C_{2j}	C_{2M}
3	C_{31}	C_{32}	C_{33}	C_{3j}	C_{3M}
.					
.					
.					
.					
i	C_{i1}	C_{i2}	C_{i3}	C_{ij}	C_{iM}
.					
.					
.					
.					
N	C_{N1}	C_{N2}	C_{N3}	C_{Nj}	C_{NM}

An estimate of the cost of activity A derived from a random sample of m time units each time unit including all N individuals is

$$C_A = (\text{Sum of } C_j Y_j) \frac{M}{m}$$

For example if N = 1, M = 2400, m = 40, salary = $60, and 30 sheets show activity A, then

$$C_A = \frac{\$60}{2400} \times 30 \times \frac{2400}{40} = \$45$$

For N = 20 individuals each with a weekly salary of $60, m = 40, and 500 sheets with activity A

$$C_A = \frac{60}{2400} \times 500 \times \frac{2400}{40} = \$750$$

Another way to obtain the same estimate is as follows since there are a total of 40 x 20 or 800 sample data sheets of which 500 show activity A

$$C_A = \$60 \times 20 \times \frac{500}{800} = \$750$$

Sampling error in estimate p_A. - Assume an unrestricted random sample in which m time units and n persons are selected at random from an MN matrix. Then an unbiased estimate of the proportion of time spent on activity A is as follows:

$$p_A = \frac{\Sigma\Sigma\, X_{ij}}{mn}$$

where $\Sigma\Sigma\, X_{ij}$ is simply a count of the number of cells in mn with activity A. The sampling variance of this estimate is as follows:

$$s^2 = \frac{(MN - mn)}{(MN)} \frac{p_A\,(1 - p_A)}{mn - 1}$$

If mn is small compared with MN then the factor $\frac{MN - mn}{MN}$ can be neglected.

Example: Estimate p_a and s when 50 persons (N) are sampled once per day for 20 days ($M = 20 \times 480 = 9600$). Let $m = 20$ and $n = 4$. This will give 80 data sheets; assume 16 show activity A. Then

$$p_A = \frac{16}{80} = 0.20 \text{ and } s^2 = \frac{(.20 \times .80)}{79}$$

$$s = .04$$
$$2s = .08$$

95% limits = $.20 \pm .08 = .12$ to $.28$

If random sampling is restricted to M, and not to N, then a cluster sample of size m results, each cluster consisting of N persons. An unbiased estimate of the proportion of time spent on activity A is as follows:

$$p_A = \frac{1}{m} \Sigma p_j$$

where p_j is the proportion of cells in the jth column with activity A. The sampling variance of this estimate is as follows:

$$s^2 = \frac{M - m}{Mm(m - 1)} \Sigma(p_j - p)^2$$

where p is the proportion of all cells in the sample with activity A and p_j is a proportion for each of the several columns (clusters). The factor $\frac{M - m}{M}$ can be neglected if m is very small compared with M.

$$p_A = \frac{1}{m} \Sigma p_j$$

If $m = 10$, values of p_A might be

.09	.25	
.15	.08	
.12	.16	$p = .146$
.20	.18	
.11	.12	

Let $M = 20 \times 480 = 9600$. Then the factor $\frac{M - m}{M}$ can be ignored.

$$\text{Hence } s^2 = \frac{\Sigma(p_j - p)^2}{m(m-1)}$$

$$s^2 = \frac{\Sigma(p_j - .146)^2}{10 \times 9}$$

$$s^2 = \frac{.02524}{90} = .000280$$

$s = .017$ hence $2s = .034$ and the 95% limits are

$$.146 \pm .034 = .112 \text{ to } .180$$

Sampling error in estimate of aggregate cost C. - For cluster sampling

$$C = \frac{M}{m} \sum_{1}^{m} x_j$$

$$s^2 = \frac{M(M-m)}{m(m-1)} \sum_{1}^{m} (X_j - \bar{X})^2$$

$$\text{where } \bar{x}_j = \frac{\Sigma x_j}{m}$$

In the following example the entries in the C matrix are unit costs for those engaged in activity A when each of m random time samples was taken.

Activity A

m = 10

	1	2	3	4	5	6	7	8	9	10
1					.02			.02	.02	
2	.02		.02	.02	.02		.02		.02	
3		.03				.03			.03	
4	.04					.04			.04	
5			.03				.03			
6				.02	.02			.02		
7										
8										
Total	.06	.03	.05	.04	.06	.07	.05	.04	.11	0

The basic values are as follows:

$$M = 10 \times 480 = 4800$$

$$m = 10$$

$$\Sigma X_j = \$.51$$

$$\bar{X} = \frac{.51}{10} = .051$$

The estimate of the cost of activity A is

$$C = \frac{10 \times 480}{10} \times \$.51 = \$244.80$$

The sampling error is calculated as follows:

$$s^2 = \frac{M^2}{m(m-1)} \Sigma(x_j - \bar{x})^2$$

$$s^2 = \frac{4800^2}{10 \times 9} \times \Sigma(x_j - .051)^2$$

$$s = \$34.36$$

$$2s = \$68.72$$

The 95 percent limits are

$$244.80 \pm 68.72 = \$176.08 \text{ and } \$313.52$$

* No statements contained herein are to be taken as official pronouncements of the Internal Revenue Service. In the section on work sampling the writer has used at several points materials prepared by H. E. Outerman and A. J. McKeon.

Notes

(1) "Audits by certified public accountants" New York: American Institute of Accountants, 1950. P. 10.

(2) E. T. Magruder "Statistical Methods for Appraising Public Utility Property." Quality Control Convention Papers - 1954. pp 27-41. See also Magruder, "Sampling Applied to Accounting Problems." 1956 Middle Atlantic Conference Transactions, A.S.Q.C. pp 79-96.

(3) B. M. Rowles, "Application of Statistical Sampling Techniques to LIFO Inventory Valuation," The Accounting Review, vol. XXIX, (April, 1954) 244-250.

(4) Winston C. Dalleck "Quality Control at work in airline accounting." Quality Control Convention Papers - 1954. pp 489-498. See also Dalleck "Quality Control at Work in Airline Accounting." 1956 Middle Atlantic conference Transactions, A.S.Q.C. pp 139-140, and an attached paper by same title pp 1-8.

(5) Robert M. Trueblood and R. M. Cyert "Statistical Sampling applied to the aging of accounts receivable," The Journal of Accountancy, vol. 97, (March, 1954) 293-298.

(6) K. W. Halbert, "The application of sampling techniques in controlling quality in clerical work," ASQC meeting, Philadelphia, February 11, 1950. Also, "Application of Sampling Inspection Plans in the Verification of Clerical Work," New York: American Telephone and Telegraph Company, Comptroller's Department, 1947.

CHI-SQUARE, HORSE KICKS AND A PLANT PROBLEM

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Briefly, the question is what is a good measure of a change or improvement in the characteristics of a product if the quality being evaluated is distributed in the manner of the Poisson. The Chi-Square test offers an objective test of such a shift in the data.

The number of flaws, defects or what-have-you, in a given length of a full coil of aluminum foil gives us an occurrence of isolated events in a continuous web. Here the number of times the event occurs can be counted without having to ask how many times the event did not occur. This characteristic fits in with the description of the Poisson distribution which applies when count is made of the number of occurrences of an event which had many opportunities to occur but is extremely unlikely to occur at any given opportunity. The area of opportunity for occurrence is kept fairly constant in this problem by maintaining the coil sizes about the same.

As many of you know, the favorite example of the experts for illustrating the Poisson Law concerns the data collected by Bortkewitsch in 1898. He calculated the chances of a Prussian cavalryman being killed by a horse-kick in the course of a year.

TABLE 1

No. of Deaths per year per Corps	Frequency Corps-Years	Predicted Probability
0	109	0.55
1	65	0.337
2	22	0.103
3	3	0.021
4	1	0.003

If you can remember a cavalry corps, you can picture the many contacts (many opportunities for kicks) the cavalryman had with his horse during a year; yet it was very unlikely the horse would make a fatal kick at any particular contact. This embraces the concept of the existence of large "sample size" n and small value for probability of occurrence p.

Our plant problem arose after a study had been made of the process as it was running. We enumerated how often a particular flaw occurred in a large population of coils, recording how many coils had 0, 1, 2, 3... defects. From this data the probability of occurrence and average number of flaws per coil were calculated, Table 2.

Management was dissatisfied with the relative frequency of such a defect. As a first attempt at improvement (with little cost) an operator training program along with tightened supervision quickly gave these results, average occurrences per coil = $\bar{c}$ = 0.353, Table 3, Columns 1 and 2.

TABLE 2

1 No. Defects Per Coil	2 Frequency	3 Probability Distribution
0	279	0.657
1	103	.243
2	34	.080
3	8	.018
4	1	.002
5	0	--
Total	425	1.000

Average = $\bar{c}$ = 0.468

TABLE 3

1 No. Defects Per Coil	2 Improved Frequency	3 Probability Predicted	4 Frequency Expected	5 Chi-Square
0	161	0.657	142	2.820
1	38	0.243	52	3.769
2	11	0.080	17	2.118
3	4 } 5	0.020	4	.250
4	1)			
Total	215	1.000	215	8.957

It was apparent from the new data that there had been an improvement. But was the change significant? The appropriate test was made by means of chi-square.

The chi-square technique in effect tests whether the observed frequencies in a distribution differ significantly from frequencies which might be expected on the basis of some prior knowledge or hypothesis.

The method is applied by calculating the expected frequencies of the events, Table 3, Column 4, on the basis of the theory being tested, Table 2, Column 3 and Table 3, Column 3. In this case we are testing whether the "improved" process, Table 3, Column 2, is significantly different from previous experience. If the test does not prove significant, then the differences noted are probably due to random error.

If we let E be the expected frequency for any class, Table 3, Column 1, and O the observed, then chi-square is calculated as the summation over all classes, Table 3, Column 5:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

The larger the value of chi-square, the stronger the evidence against the hypotheses. But, how big must chi-square be before we have a difference between observed and theoretical frequencies which is not explainable by chance? This depends on the degrees of freedom.

Here the degrees of freedom equaled the number of classes minus 1 or 4-1=3. Entering the chi-square table with 8.957 from Table 3, Column 5, and 3 degrees of freedom, showed that there had probably been some improvement in the process (probability value approximately 0.03).

The process was allowed to continue at this new level for a short time sufficient to determine the new probabilities, Table 4, Column 3, and new average $\bar{c}$ = 0.333.

Since this amount of improvement was not deemed sufficient by Management, a process change was instituted and new data collected, Table 4, Column 2.

TABLE 4

1 No. Defects Per Coil	2 Improved Frequency		3 Probability Predicted		4 Frequency Predicted	5 Chi-Square
0	132		0.733		111	3.973
1	14		.196		30	8.533
2	3	5	.056	.071	10	2.500
3	1		.013			
4	1		.002			
Total	151		1.000		151	15.006

This time the chi-square table (with 2 degrees of freedom) showed a highly significant change (probability less than .001). Management was satisfied by this latest distribution of defects and with the average per coil $\bar{c}$ = 0.079. This ends the discussion of the particular plant problem.

Following are a few additional comments on the approach used:

1. The chi-square distribution as used here tested the goodness of fit of a theoretical distribution and observed data. This could have been done by testing the mean and variance employing other methods, but chi-square is a more detailed approach because it takes into account, not only a couple of parameters, but the overall shape of the distribution.

2. Speaking about the shape of the distribution, we could have made all our comparisons against the standard Poisson distribution rather than the distribution actually created by the process since the defect characteristic occurred in the manner of the Poisson. In fact, our first checks were against Poisson and gave comparable results. However, we were able to make the chi-square test more powerful by using the actual process distribution or shape and not the Poisson approximation of it.

3. Personally, I found the determination of the proper degrees of freedom to be the most difficult phase in applying the chi-square test. The degrees of freedom are determined by counting the number of independent restrictions placed on the theoretical frequencies when they are being determined and subtracting this number from the number of comparisons (classes) made between theoretical and actual frequencies. For example, if we had compared our observed distribution with Poisson, we would have lost 2 degrees of freedom; 1 by making the total number of cases or events the same and 1 for taking the theoretical mean (the only parameter needed to define a Poisson) the same as the observed mean. On the other hand, since in this problem the

only use made of the observed data in calculating the expected frequencies was to determine the total number of cases (the shape of expected distribution being set by prior knowledge of the process), there was only 1 degree of freedom lost.

4. As will be noted in Table 3, Column 2 and Table 4, Column 2,it was necessary to lump the several classes in the diminishing tails together. This follows a rule requiring the frequency in any class to equal 5 or more.

5. A control chart for defects per unit (c-Charts)could have been used to detect the shifts in levels in our problem but it would have taken a longer period of time than we were allowed to prove that there had been definite shifts.

6. The approach used in this problem is handy whenever decisions must be based on enumerative data such as:

Defective rivets in a metal product
Defects in a bolt of cloth
Breakdowns in insulation in a given length of wire
or the incidence of a defect in a unit of product.

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QUALITY CONTROL APPLIED TO CLERICAL OPERATIONS

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It has been proven in many industries that the use of statistical methods, under competent guidance, results in greater output, plus the competitive advantage of better quality, more uniformity, less waste and greater dependability of product. Amazingly these techniques usually take place simultaneously with reduced cost in production, and without expansion of the facility. For still more effective use of these methods, management should not only become familiar with the results of statistical methods; they should also study the problems of organization by which to take advantage of a wider and better use of these methods.

The utility value of statistical methods to management has been very aptly evaluated by Mr. William B. Rice, a consultant in the Los Angeles area:

> "First, a change in trend (especially significant when a transition period is approaching) usually manifests itself in a statistical study before it otherwise becomes apparent. Second, the limits above and below a trend define the normal area of fluctuation. Any point falling beyond these limits is usually indicative of some sort of a maladjustment which should be investigated. Third, statistical analysis forces factual thinking and logical approaches to all kinds of problems. Finally, and perhaps the most important, statistical conclusions can and should be used to confirm and check the conclusions reached by the exercise of good subjective judgment. With statistical guideposts set up for sales, costs, and production, management can not only keep itself well informed, but can also set intelligent and practical goals, the attainment of which can be guided within the limits of what is economically possible. Thus the company can achieve its aims consistently, steadily, step by step, with a minimum of effort and expense."

The impact of statistical theory during the past 12 to 15 years has been so great that it has affected and altered practically every human activity in production, business, government, and research. Wherever statistical techniques have been applied with competence and conviction, the results have invariably been increased production and other advantages previously mentioned.

Perhaps, the most common or widespread use of statistical methods is in the control of quality - in both the production and office areas of industry. As was true in the case of job evaluation, work simplification, time study, merit rating, etc., the office has lagged behind the factory in the application of the principles of quality control. However, there are some companies that have done some excellent work in this area. Those that we know of include Alden's Inc., United Airlines, Illinois Bell Telephone Company, B. F. Goodrich, General Electric Supply Company and the Prudential Insurance Company.

In the quality control programs in any of our office departments, our first step is to explain the fundamental or basic principles to the employees involved. Also, we outline the steps that will be followed in developing and setting the program in motion. These details or steps of necessity vary from department to department due to the varied nature of the work done. Basically, however, they follow this general pattern:

1. Establish a definition and classification of errors.
2. Determine the current outgoing quality level of the operation.
3. Establish inspection stations whereby quality may be checked.
4. Establish sampling plans that enable us to get a true cross section picture of the work.
5. Design work sheets to be used in recording inspection data.
6. Designate personnel to be quality control inspectors.
7. Establish the control charts proper.

We also have meetings with the employees from time to time as developments take place, in order to keep them fully informed as to the progress they are making, and also to make them feel that they are participating in the formulation and the development of the program.

We determine the current quality level of the particular operation in question by means of recording the results of the 100% verification of the work involved. After this determination has been made, we are in a position to make the decisions necessary to the establishment of a sampling plan that will fulfill the requirements set forth by the departmental and divisional management. These decisions are:

1. Quality of work that is acceptable.
2. Quality of work that is unacceptable.
3. The risk or cost of verifying work which is already of an acceptable quality.
4. The risk or cost of not verifying work of an unacceptable quality.

Taking these four factors into consideration, a sampling plan is then designed that will fulfill the requirements set forth by the interested parties.

In administering the sampling plan, after it has been designed, our Quality Control Inspectors are instructed to keep three factors in mind: 1) regularity, 2) randomness, and 3) thoroughness.

The inspectors, lay employees in the department, are under definite instructions to take the samples at regular intervals. They do not take samples at the same time each morning and afternoon or each day, but do take a sample from every group of work units that are processed through the department. This is necessary to aid the employees in maintaining control, and also to keep the department manager informed of the current quality level.

The regularity of the sampling also serves as a constant reminder that quality is an ever-present problem, and not a matter which can receive occasional attention. The Quality Control Inspectors are also

instructed to select the samples in a random manner. Complete randomness is difficult to achieve, but the inspectors try to select samples in such a manner that each invoice has the same chance of being inspected. If the control chart proper is to indicate an accurate picture of the quality level, the employees must not know at any time which units of work are to be inspected.

In other words, the control chart will show a record of what is being accomplished at all times, and not just when the employees are being particularly careful with their work. Thoroughness is brought into the sampling plan by designating employees who have full knowledge of all the details connected with the operation to be inspected. They are employees who have the necessary knowledge and experience. Instruction sheets giving the details and particulars of the particular procedure and sampling plan under which the inspector is operating, are furnished each inspector for his guidance in administering the sampling plan.

Using the sampling plan designed around the four factors involving acceptability and risk, the inspectors begin sampling the work and record the results of this sampling on a data sheet. The number of units inspected and the number of defective units are recorded by individual, and then totaled for the over-all departmental performance. A record is kept on the description, frequency and responsibility for the errors that are made.

Provision is made for the review of this data by the Department Trainer, Department Manager, and Office Management Division. From an analysis of this data and certain computations, the control chart is established and posted on a regular basis.

The control chart, as adapted to our use, takes a positive rather than a negative approach by indicating the amount of good work performed rather than the number of errors committed. We believe that this approach strengthens the psychological benefit to be derived from the control chart that is placed where it is visible to all employees of the department and will help our department heads to be good managers by creating a competitive spirit among the employees of their departments by encouraging them to "break" the top of the chart.

A vertical scale along the left margin of the chart is a measure of the good work performed which we have termed as the percentage of efficiency. A horizontal scale along the bottom of the chart is a measure of the time intervals of the sampling procedure. A solid black line is indicative of the current average quality level of the particular operation. A dotted or broken line indicates the control limit, or, as we prefer to think of it, the "take action" line. When sample plottings fall below this line, investigation of the operation is immediately begun so as to "bring to light" the cause of the lowering of the quality, and the necessary remedial action is taken.

It is important that the results of the sampling be posted on the control chart immediately. Unless this is done, the necessary action may not be taken quickly enough to avoid making more errors of the same type. Also, if the results posted indicate that the desired control is being maintained, that information, being made immediately available to the department manager by consulting the chart, gives him assurance.

In order to provide the department manager with another managerial working tool, an Employee Quality Control Rating card is provided for each employee in the department. This card provides for a comparison between the individual's performance and the over-all performance of the group, and also for a classification of the errors made by each individual. The errors are coded numerically, in order to conserve space, on a 3" x 5" card, and the code legend is printed on the reverse side of the card. These cards are posted on a monthly basis, and can be used by the department manager as he sees fit, i.e., either to command or reprimand employees.

It is well known in the accounting profession that accountants generally base their conclusions on samples of accounting entries. However, this practice is often misunderstood by the layman because of the many but accepted varying auditing procedures that depend largely upon the good judgment of the individual auditor. The prime condition to be satisfied in any of these varying procedures is that the responsible auditor be satisfied as to the adequacy and accuracy of the audit. But the means by which he accepts the accuracy and adequacy of the audit are for the most part his own.

Therefore, there are bound to be varying circumstances which may influence an accountant or auditor to either accept or reject the conclusion that the audit is adequate and accurate, and these various circumstances will influence each individual to a different degree. The degree to which the individual may or may not be influenced varies, depending upon his own ideas, the mood he is in, and the pressure of this current work load. We do not mean to suggest that by the use of statistical methods, the auditor will not have to make decisions or pass judgment, but we believe the use of such methods will allow the auditor to arrive at a conclusion without being influenced by the above mentioned factors. Also, statistical methods will permit the auditor to:

1. Establish with assurance more specific and effective auditing standards.
2. Predetermine the amount and the cost of the work to be done.
3. Plan his work more accurately or exactly.

The auditor must determine upon his analysis of the sample to either accept or reject a group of entries, computations, or postings, the same as a receiving inspector must determine whether to accept or reject a shipment of items from a supplier. By establishing certain quality standards and risk factors, the accuracy of a group of entries, postings, or computations may be determined by an analysis of a sample taken from the group with the assurance that the interpretation will be mathematically sound.

Statistical methods also put the auditor in a more favorable position to make recommendations with regard to checking the work of a given department after he has made an audit of their work. Such methods provide the auditor with a measure of the performance of the department in terms of the probability of selecting a sample of a certain number of erroneous units from a satisfactory group of units; and it also can be easily shown that poor performance requires the selecting of more samples, therefore increasing the work of the auditing

staff. We believe that it is also obvious that a specific set of quality standards places the auditor in a more favorable position since it relieves him of the possible criticism of being too cautious or not cautious enough, and also takes from him the pressure of making a more favorable report than he would like to make by placing the responsibility for such a decision upon impersonal mathematical principles.

One of the major reasons contributing to the delay of a general acceptance of auditing standards by the accounting profession has been the fact that there has been no method for specifying the size of the sample to be taken. Therefore, the feeling that any such specification was certain to be arbitrary was inevitable. The mathematical reasoning available in statistical sampling methods should eliminate this particular objection.

In statistical sampling computation of probabilities enables us to come to some conclusion with regard to the items being sampled, within a certain confidence interval as has been prescribed by the predetermined risks that we have decided upon. In other words, we can arrive at a conclusion with regard to a population from an analysis of a sample by 1) making an estimate of population's quality level; 2) computing the probability of drawing the sample from a population of such a quality level; 3) accepting or rejecting the estimate according to whether our probability computations indicate the sample to be a common or rare one from a population of the estimated quality level.

The statistical reasoning or logic that we have discussed requires the establishment of a level of probability upon which the decision is to be made, as well as a standard of acceptable quality and unacceptable quality. If no restrictions are set forth, each auditor may choose his own probability level just as he now decides by his own standards to either accept or reject a set of entries as accurate or not. However, statisticians have generally used levels of 90% to 99% as a basis for decisions. As the level of probability is raised, the cost of sampling also rises; and as the probability level is reduced, the risk of accepting substandard populations as standard or better increases. Our experience leads us to suggest a 90% probability level for auditing applications as being reliable and economic.

Use of probability levels as a practical working tool is made easy by the development of sequential analysis. This method was developed during World War II by the Statistical Research Group of the Applied Mathematics Panel of the National Defense Research Committee. This group based their work on the mathematical principles envolved by a mathematical statistician named Abraham Wald.

A sequential sampling plan is determined by establishing four values which are then called the operating characteristics of the plan and which have been described previously. Once the two quality values and the associated risk values have been decided upon, it is possible to mathematically design a sequential sampling plan in which the specified risks of making wrong decisions concerning the specified acceptable and unacceptable quality of work will be met.

As in any application of the laws of probability in sampling theory, the use of a sequential sampling plan does not attempt to state exactly what the percentage of defectives or errors in an actual population is. This could be done, of course, only by verifying all items in the population. It does, however, enable the auditor to come to a conclusion about the actual population on objective grounds, and also enables him to make a decision, by the use of mathematical logic, that the particular area of the accounting operation is or is not apparently satisfactorily accurate.

As we have stated earlier in this discussion, there is probably no development gaining more favor in business today than the application of statistical methods--and the statistical sampling technique is probably the most used of such methods. Every executive will be calling on these tools, and of necessity must prepare himself to use them.

The value of the properly developed sample lies in the probability that it adequately reflects and describes a large body of facts. The skeptic must remind himself that even a 100% record of a body of facts enjoys only a probability of reliability. And where a body of facts is changing, the time consumed in obtaining a 100% record will affect the validity of the results. Therefore, if unnecessary "accuracy" can be sacrificed in exchange for speed, timeliness, and completeness, the sample is appropriate. In fact, in a dynamic situation, the sample may be the only means of achieving highly valid criteria upon which to base executive decisions.

The statistical sample is both complex in theory and mathematical derivation, but simple in application. We had adapted methods of sequential analysis to some of the problems of our internal auditor--that is such methods were used to determine whether or not certain phases of our operation were "up to" some predetermined level of accuracy. However, the time came when the internal auditors wanted to make a statement with regard to the accuracy of a "file" within certain tolerances and within certain associated degrees of risk.

The procedures of acceptance sampling that have been discussed previously, will not permit the making of such a statement. For example they will tell us that a certain population is 5% or less defective, or that it is more than 5% defective. However, they cannot tell us how much better, or how much worse the actual quality level is, as compared to the predetermined standard level of accuracy desired.

The technique of sampling for proportions permits the following type of statement to be made--"the true value of the percent of error in our shipped order files is 8% plus or minus 1-1/2%--i.e., the true value of this proportion will fall between 6-1/2% and 9-1/2%--90% of the time." This is the type of report that our internal auditors are called upon to make from time to time.

Before a sample size can be computed, it is necessary for the individual desiring the information to make the following decisions:

1. The permissible tolerance in the proportion that he is willing to allow.
2. The risk that he is willing to assume that the sample will not reflect a true picture of the population being sampled.

3. His estimate of the proportion.

Once these decisions have been made, a sample size may be computed, and the results of analyzing the sample interpreted as outlined in the example above.

A companion or comparable type of sampling to that just described is sampling for average values. Again, in order to make use of this statistical sampling technique, the person desiring the information on a sample basis must make the following decisions:

1. Permissible tolerance he is willing to allow in the average value for which he is searching.
2. The risk that he is willing to assume of coming to an erroneous conclusion.
3. The dispersion or range of the value of the items being sampled.

Again when these decisions have been made, a sample size may be computed that will fill the requirements set forth.

By using both of these sampling techniques, that is sampling for proportions and sampling for average values, the person making the analysis of the sample may make statements with regard to the proportion or average value that will be within the predetermined allowable tolerances as specified by the associated, predetermined risks. The greatest use of these techniques in our organization has been in our Internal Auditing Department. However, our Office Manager has also made use of them in order to obtain timely data upon which to base decisions regarding the changes of methods and systems, and also in order to compare the costs of one system as compared to another before actually making such a change.

We believe that an objective viewpoint must be taken in considering the problems of either quantity or quality of office work. These procedures must take into consideration the fact that production rates and the quality ratings of the same or different workers are always subject to a certain amount of variation. One of the major functions of these procedures should be to provide a method which will answer these two questions:

1. When can these variations be attributed to random causes?
2. When are the variations caused by assignable causes?

Methods which will enable us to distinguish between chance causes and assignable causes thus perform two important functions. When they indicate that all of the variations can be considered as being due to chance, or random, causes a state of control or stability can be assumed. When the methods show, however, that assignable causes do exist, then conversely, a state of control or statility does not exist.

The variables involved in quality problems are much more limited than the variables involved in production problems. There are probably several reasons for this, all dependent on the fact that quality is itself a variable with respect to production rates. For example, quality is affected much less by the variables brought to the work

place by the worker than is production. This is due partly to the fact that an employee's primary interest is in production rather than in quality. The result is that statistical control procedures used in quality problems have to be modified for uses in connection with production or work measurement problems.

We prefer to use the term stability, rather than the term control, in connection with production or work measurement problems for several reasons:

1. It helps to distinguish (in every day terminologies) between quality and work measurement problems.
2. It emphasizes the fact that the procedures used in these two types of applications are not necessarily identical.
3. The term stability has a greater degree of descriptive value than the term control when used in connection with work measurement rates and problems.

The first step in our procedure is to decide on a sample size. In making a variable study, most authorities such as Shewhart, Grant, Duncan and many others, recommend a sample size of at least four units. We do not and cannot quarrel with this because it is based on the fundamental and proven statistical theorem that the distribution of sample means approaches the normal distribution as the sample size increases--regardless of the nature of the population being sampled.

However, because of the small number of units of data that we occasionally have available to us, we have in some cases used a sample or subgroup size of three. As small a sample size as this can have certain advantages in that there is a smaller risk that significant changes will be hidden when only a few units of data are available.

The next step is to group the individual units of data into subgroups of four or five units each. As previously stated, we have occasionally used subgroup sizes of three when the extent of our basic data is not too great.

The third step is to determine our criterion of stability. In most cases, we use the conventional three sigma limits usually used in quality control work. The stability limits are computed from the conventional formula:

$$(1)\quad USL_{\bar{X}} = \bar{\bar{X}} \pm A_2 \bar{R}$$

in the case of the chart for means, and from the conventional formula:

$$(1)\quad USL_R = D_4 \bar{R}$$

$$(2)\quad LSL_R = D_3 \bar{R}$$

in the case of the control chart ranges. In these formulas, $\bar{\bar{X}}$ is the mean of the sample means, and $\bar{R}$ is the mean of the corresponding sample ranges. A_2, D_3, and D_4 values for the subgroups are obtained from tables available in many texts on statistical control. Next, the means and ranges of the subgroups are plotted against the stability limits. If all the plottings fall within the stability limits of the variations among the means and ranges can be considered stable--that is, the variations are due to chance or random causes.

If the charting results in determining that the process is stable, it is possible to use the $\bar{X}$ value as an estimate of the mean of the population production rate. Also the $\bar{R}$ value can be used to estimate the value of variability in the population production rate.

Thus, control chart studies provide specific and exact information with regard to the statistical properties of production rates, provided, of course, that stability has been established. With this information, production rates can be compared to determine whether some personnel need additional training, whether better equipment is required, whether methods and procedures need revising, whether a new layout is essential, etc. Establishing stability also has the advantage that it enables us to make valid estimates of future production rates as well as the limits of their variation. In addition, we can expect that the means of the subgroups of data will fall within the stability limits about 99.7% of the time.

If stability does not exist, such estimates and predictions or forecasts cannot be made--that is, you have a state of unpredictability. In such cases, it is necessary to isolate and eliminate the assignable causes responsible for the excessive variations. The elimination of assignable causes serves two major purposes. First, it is necessary to eliminate assignable causes to bring about stability, without which estimates and forecasts are impossible. Also, assignable causes are usually economically undesirable, and their elimination usually increases the uniformity of production and decreases the mean value of the productive rate. However, we should also point out that assignable causes are sometimes economically desirable. If the points fall in the low side of the stability limit, the assignable causes may "point up" an improved method which could be profitably employed in the operation on a formalized or systematic basis.

In operations controlled by human beings, assignable causes are often temporary, such as that which occurs when a person's attention is distracted. For this reason it seems logical or reasonable to us to allow several points to fall outside the stability limits in office work measurement programs, and still consider the process or operation as being stable.

We have found the more important advantages in statistically developing work measurement programs to be:

1. It provides an objective rather than subjective approach to the elimination of interferences with an operation.
2. Statistical stability makes it possible to make estimates and prognostications of future production performance.
3. Such estimates, in turn, permit an evaluation or comparison of actual production rates and the requirements of the operation. If this is not a favorable comparison, adjustments and changes must be made.
4. Provides an insurance that production rates remain at a stable and economic level--the cost of which is negligible because of the drawing of samples with decreasing frequency until they are taken only occasionally.

The field of statistics has made rapid progress in the development of statistical theories and the application of those

theories to practical problems. However, the progress of statistics is not entirely due to the efforts of statisticians. To a certain extent it has been influenced by the growth of our economy--that is, as the economy expands, it demands more and more scientific and objective rules of behavior. The statistician and mathematician have had to search for new procedures or broader uses and revived applications of old formulas. American business, in general, is decentralizing to the extent that the home or main office can no longer exert the close control necessary by subjective means. There is a need for objective control over every phase of growing industries.

There is also little doubt that the old adage--"Necessity is the mother of invention"--has also been responsible for many of the new techniques that have been and are being developed to reduce the cost of controlling and managing the expansion of American business. To name a few, there are statistical sampling, operations research, linear programing, econometrics, sequential analysis, theory of probability, etc., etc. The usefulness and practical value of many of these and other techniques have been demonstrated in actual business practice. Some are in a stage of being developed for application to practical problems, while others are still in the theoretical stage of development. It would, in our opinion, be advisable for management to at least familiarize themselves with the principles of these techniques and their variety of possible application or adaptation, because in one way or another, they all have, or will have some use in the field of business. Some management personnel are aware of these techniques, and have adopted some of them here and there. However, even though the techniques have been proven sound, they are still not used generally. A word of caution in this connection seems advisable at this point--be sure to avoid the use of techniques that do not have "their feet" on sound theoretical ground. That is, be sure that the mathematical logic behind the method has been proven by the mathematicians.

In our opinion, statistical knowledge can contribute much to the maintenance of private enterprise, which must depend more and more on the continuous improvement of the efficiency and the effectiveness of its sales, office, production, research, and financial operations.

A MUTUAL APPROACH TO QUALITY CONTROL BY CAN MANUFACTURER AND FOOD PROCESSOR

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This paper describes a cooperative effort by canmaker and food processor in solving a quality problem common to both, namely the reduction of processed product spoilage. It must be stressed that the success of this program resides, to a great extent, in the fact that it was developed mutually. It is also noteworthy that the program evolved into its present form over a period of years, with the technical facilities of both organizations being utilized in its development and frequent modification.

The program is composed of two phases, (1) the control of top double seam formation, and (2) the sampling and evaluation of incoming cans. Before covering the essential details of this program, it seems appropriate to define the basic processes involved and describe product spoilage.

Can manufacturing consists of the conversion of tin coated sheet steel into finished cans. Canning (for the purpose of this paper) consists of (1) the packing of food products into hermetically sealed containers (cans), and (2) complete sterilization of the can and contents. Spoilage is the bacterial decay caused occasionally by incomplete sterilization but, generally, it is caused by recontamination or leakage through some defective part of the can. Cans may be defective either by reason of poor can manufacture, poor top seam formation, or excessive or rough handling. Generally, the combination of defects with rough handling produces spoilage.

When a can spoils it swells and may eventually burst, spilling its contents onto other cans in the stack, making them unmerchantable by reason of exterior corrosion. If allowed to go unchecked, these will, in turn, rust through, thus pyramiding the spoilage. This so-called secondary spoilage has been known to run into tremendous losses.

The problem of spoilage control is of joint concern to both the can manufacturer and the food processor, because the spoilage losses are borne by both. The can manufacturer is liable for spoilage caused by any defective part of the can, other than the top seam itself, and the food processor is liable in the case of top seam leakage.

TOP DOUBLE SEAM CONTROL

Extensive examinations of spoiled cans have shown that a major cause of container leakage is faulty closure; i.e., poor formation of the top double seam. Thus, at the time that this overall program of spoilage control was launched, it was very apparent that the first attack must be aimed at improving the quality of this seam.

In past years, attempts at controlling the formation of the top double seam were haphazard, at best, in many food processing plants. Specifications, many of which were entirely subjective, were based on the experience of the can manufacturers and closing machine operators

and were often loosely applied. It is probable that there was over-controlling in some plants and under-controlling in others.

The quality of work turned out by the closing machine department was not fully evaluated until long after pack, when a substantial portion had been sorted and the spoilage rate estimated. Obviously, very little control was possible under these circumstances and, since the loss due to spoilage was often staggering, a system of on-the-spot evaluation of the top seam was established, with subsequent control procedures.

In order to adequately describe this program, it is first necessary to define the main characteristics of a good double seam:

1. In cross-section, the seam should appear about as it does in Figure I, which also shows some of the terminology used. It is important that there be sufficient engagement or overlap of the body and end hooks.
2. The outside of the seam must be smooth, with no irregularity, and the curled edges or radii should be well rounded. A sharp edge at the seaming panel radius indicates too tight rolling, which can fracture the plate at this point.
3. The face of the end hook should be smooth but without a "drawn" appearance. Wrinkles indicate a loose seam and a drawn appearance indicates a seam which is too tight. The end hook, as it is examined, (after seam is torn apart) is shown in Figure II.
4. The weakest point of a double seam occurs at the side seam juncture or lap. There are two extra layers of plate and a quantity of solder here, all of which add to the difficulty of making a good seam. Because of this extra metal, it is more difficult to properly tuck the end hook up at this point, and there is nearly always a certain amount of "droop" in the end hook, as shown in Figure III, which must be held to a minimum.

Seam tightness, hook length, overlap, etc., can all be varied by machine adjustments and it is apparent that there can be all degrees of variation. Furthermore, it should be noted that a can with a loose seam will not necessarily leak and spoil but, as a seam becomes looser, the probability that the can will spoil increases. Attempts to determine this probability have met with very little success, probably because of the impossibility of controlling the other factors. While the problem of determining just how severe these defects should be allowed to get before shutdown and machine adjustments are warranted has not been fully solved, it has been definitely established that there are certain specifications which, if met, will yield a minimum of spoilage. Specifications originally set up for the control program were based on the combined experience of many people and were changed as additional data was gathered in the course of the first few years of the operation of this program. It is interesting to note that, as more experience was gained, the latitudes of many of these specifications were increased considerably beyond the actual machine capabilities which, of course, reduced the amount of controlling necessary.

A sampling schedule was set up for each type of closing machine and was closely adhered to. Samples from each machine are checked (non-destructive tests) every fifteen minutes for external defects, such as

FIGURE I

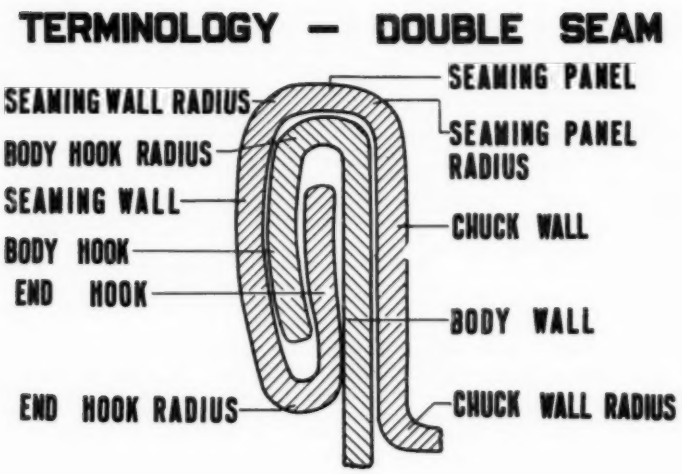


FIGURE II

DOUBLE SEAM TIGHTNESS

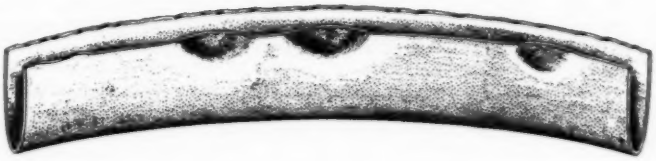


FIGURE III

DROOP AT JUNCTURE

might be caused by broken chucks or pins, or by excessively loose or tight rolls. Many gross defects, which could have resulted in very high spoilage losses, have been caught by this inspection and corrected before extensive damage has occurred.

At hourly intervals, samples are taken from each seaming head, torn down, and completely examined. The end hook is checked visually for wrinkles and rated according to the severity of these wrinkles. The end hook is also examined for droop, at the point where it crosses the lap, which can be measured with a simple plastic gauge if need be. The body and end hooks are checked with "go - no go" gauges to assure that they are in the right range. They can also be measured with a micrometer, if necessary. A cross-section of the butting is examined visually for tuck-up and overlap, and ratings are assigned to each.

It should be noted that the estimation of seam tightness is the only measurement which cannot now be made objectively. Many of the other characteristics are rated visually (e.g., the cross-section of the butting) for expediency, but they can all be checked by instruments if necessary. These instruments are used to settle differences of opinion and as an occasional check to assure that the widely separated personnel involved are using uniform visual standards of rating.

On the basis of the data taken as outlined above, the seam is classified as "A", "S", or "R", and action is taken according to the following:

"A" - Acceptable quality, no action required.
"S" - Substandard or borderline quality, adjust machine at first opportunity.
"R" - Reject quality, shut down and adjust machine at once.

The data is recorded on a form with the above rating assigned at

the bottom of each sample column. Supervisors (and closing machine operators) can quickly determine whether or not the machines are running in the "Accept" range.

As with many such quality control programs, it was necessary to "sell" both the management and the operating personnel on the value of this program. This was done by installing it in one plant under careful supervision of the Quality Control Departments of both the can manufacturer and the food processor. Spoilage in this plant was substantially reduced in one year at a low cost of control, and the value of the program was definitely established. In addition, this initial trial indicated some weak points in the program, which were corrected to make it even more effective. As soon as feasible, the program was expanded to other plants, with subsequent substantial reductions in spoilage.

As a side result of this program, several instruments and tools, many of which are power driven, have been developed to aid in the teardown and examination of the double seams.

As the spoilage due to faulty top double seam formation was reduced to a very low figure, defects in other parts of the can became much more apparent as causes of spoilage and this pointed obviously to the next area of attack.

INCOMING CAN SAMPLING

It was recognized, by both the producer and consumer, that an incoming can sampling program should be added to the program. This was directed at detecting any shipment which contained an excessive percentage of defective cans. Essentially, any such program involves the establishment of (1) a classification and definition of defects, (2) an acceptable quality level (A.Q.L.), and (3) a lot tolerance percent defective (L.T.P.D.). The latter two factors are expressed by an operating characteristic curve which shows the probabilities of acceptance versus percent defective of lots. The operating characteristic curve is a function of the sample size and criteria of acceptance, or the allowable number of defects permitted in the sample.

It proved difficult to establish a complete list of defects since, as already mentioned, the relationship between "lot quality" and "spoilage" is not exactly known. However, there are some basic structural defects which are known to have a high probability of causing spoilage, such as open laps, poorly soldered side seams, and cut-overs. These were organized into a category designated as Class I defects. Other defects, which have a relatively lesser probability of generating spoilage, were placed into a Class II defect category. These included such items as short body hooks, poor butting, and loose seams. While it was apparent that extremely loose seams, extremely poor butting, complete lack of overlap, or very short hooks could be classified as Class I defects, it was felt that, if the condition on a can manufacturing line was so bad as to produce such gross defects, there would be a sufficient number of defects to reject shipments under the Class II category.

In setting up the definition of defects or specifications, it was realized that neither the can manufacturing nor the top seam specifi-

cations could be used. This seems evident because manufacturing specifications are for "process control" and are set in accordance with machine capability. They are relatively tight in order to assure that any deviations or trends will be highlighted and remedied before the quality level deviates too far and reaches a dangerous level. For incoming sampling, the specifications used were oriented toward "spoilage", hence they were broader than the ones used for process control.

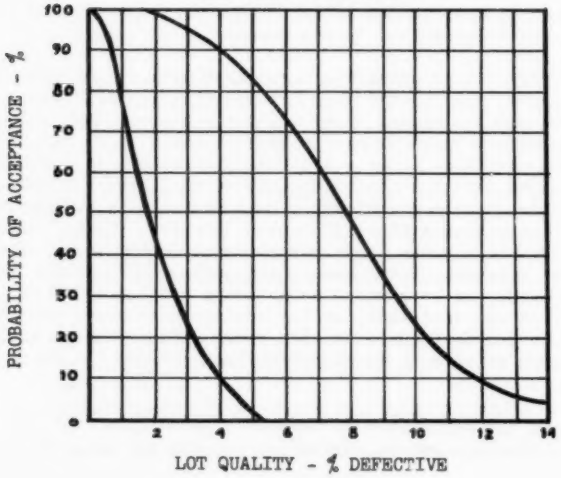
In arriving at suitable values of AQL and LTPD, a trial and error approach was used. A whole series of operating characteristic curves, based on varying sample sizes, AQL's, LTPD's, and risks, were carefully studied. As might be expected, the final choice was a compromise between the ideal and the practical, in terms of the cost of sampling and inspection. Ideally, it would have been desirable to utilize a plan which would have a large degree of discrimination, one in which the OC curve was very steep. This, of course, would maximize cost, since steepness of OC curve can only be attained through increased sample size.

There was an important factor which made it seem reasonable to reduce the sample size required. It was thought at the time, and since has been proven true, that shipments would be either very high or very low in quality, rarely being borderline. This meant that the LTPD could be set fairly far from the AQL, which lowered the required sample size.

The operating characteristic curves for the Class I and Class II defect plans are shown in Figure IV. Note that the AQL values are 0.5% for Class I defects and 4.0% for Class II defects. The LTPD values are 4.0% for Class I and 12.0% for Class II. The producer's risk was set at 5% and the consumer's risk at 10%, which are commonly used values.

FIGURE IV

O.C. CURVES FOR CLASS I
AND CLASS II DEFECTS



In order to minimize the time and cost of examination, item-by-item sequential sampling was used, instead of either single or double sampling. This type of sampling plan permits a decision to be reached, on the average, in the least amount of time.

A worksheet for this plan is shown on Figure V. The "Inspector" plots the cumulative number of defects after examining each sample. A decision to "accept" is made only after the plotted points cross into the accept zone. As long as the points remain in the "retrial zone", the evaluation continues. Note that a decision to accept the car may be made at a minimum of 63 cans, in the case of Class I defects, and 27 in the case of Class II defects. The maximum number of samples used has been fixed by truncating the sequential sampling plan at 120 cans for Class I and 115 for Class II. If the points are still in the retrial zone at this point, a decision is reached by reverting to a single sampling plan. The OC curve for the sequential plan and truncating single plan are nearly identical, so that the values of AQL, LTPD, and risks are consistent.

The program is set up so that the consumer either "accepts" or "questions" a car. When a car is questioned, a representative of the producer's Quality Control Department is called in. He draws a completely independent sample, using the same sampling plan. This is called "Referee Sampling" and the questioned car is either accepted for use or rejected on this basis. This procedure provides the producer with an independent evaluation of the shipment. The second sampling is necessary because the original samples have been torn down and new ones are required for a complete, accurate evaluation.

The first experience with this addition to the program was inconsistent with theory. Too many cars were questioned in relation to the number rejected. Most of this difference was due to differences in evaluating samples, or in non-random samples. This was remedied by realigning the list of defects and improving upon the definitions and placing greater emphasis on obtaining random samples.

Because of this program, the producer was able to analyze sampling results on rejected cars and pinpoint areas where quality deficiencies existed. The producer made a number of improvements in his quality control program and instituted appropriate engineering projects to overcome basic weaknesses. Obviously, this benefited both parties in the reduction of spoilage due to poor can quality.

Subsequent experience with this program has been very satisfactory. The number of cars questioned has been reduced by about 95% during the period in which the plan has been in operation. In addition, the discrepancy between the number of cars questioned and those rejected has disappeared.

In summary, it seems worthwhile to cite the results of the installation of this program, which can be considered successful only if its result is tangible gain or quality improvement. This spoilage control program has resulted in substantial dollar savings, well over and above the cost of its administration. The actual spoilage loss in dollars and cents, calculated on the sales value of the product, has been reduced by 75 to 80 percent as a result of this program. Other losses, such as excess handling, secondary spoilage, and consumer complaints, which

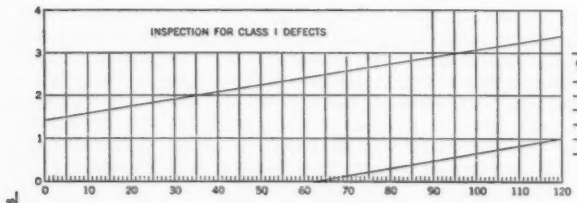
FIGURE V

REFEREE SAMPLING PLAN INSPECTION REPORT FORM — PACKERS CANS

SHIPMENT:
CAN SIZE_____
CAR NO._____
NO. OF CANS_____
DATE DELIVERED_____
MFG. PLANT #_____
BAGS OR BULK

TEST:
NO. OF CANS SAMPLED_____
NO. OF CANS INSPECTED_____
TOTAL CLASS I REJECTS_____
TOTAL CLASS II REJECTS_____

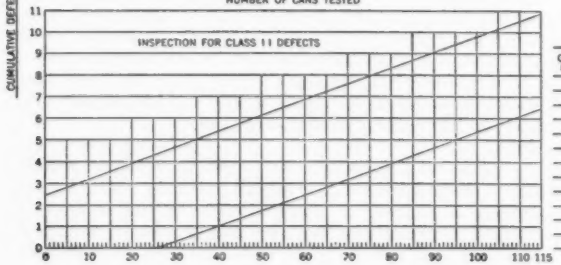
DATE_____
CUSTOMER_____
PLANT_____
LOCATION_____



DEFECTS — CLASS I

CAN NO.	LINE NO.	DESCRIPTION

NUMBER OF CANS TESTED



DEFECTS — CLASS II

CAN NO.	LINE NO.	DESCRIPTION

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REMARKS:

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INSPECTOR:_____

cannot be calculated in dollars and cents, have also been greatly reduced. Because of the extremely low incidence of spoilage which the program has effected, it is now possible to line label and double seal a large percentage of the pack, which again reduces operating costs.

In addition to the above benefits of this program, the producer has been able to better pinpoint basic quality weaknesses due to the systematic and detailed field information now available. This has functioned as a "feed back" mechanism to the producer's Research and Development Department, and has resulted in several basic improvements, both in container design and in can manufacturing techniques. These improvements have improved the quality of deliveries to <u>all</u> food processors.

These achievements have amply demonstrated that a cooperative effort between producer and consumer in the establishment of such a quality control program can be successful and prove of great value to both.

QUALITY CONTROL PLANS AND PROCEDURES OF THE DEPARTMENT OF DEFENSE

John J. Riordan
U. S. Department of Defense

Probably, it would be more accurate to entitle this paper "Some Plans and Procedures of the Department of Defense (DOD)"; it certainly would be presumptive to attempt to catalog and describe the wide variety of plans and methods that have been developed over the years by the various military departments and commands that collectively comprise the DOD. These plans, procedures and techniques have one thing in common -- they reflect the fundamental quality control policies of the Department of Defense.

QUALITY CONTROL POLICY

What are these policies? Briefly, the Department is committed basically to three propositions:

1. That quality control plans and procedures must be the outcome of calculated forethought, reflecting an analysis of requirements pertinent to a particular product or service.

2. That the DOD must utilize, to the optimum, objective, verifiable data -- particularly data generated by contractors.

3. That it is imperative to standardize, to the maximum extent, operational plans and procedures in quality control.

BROAD ADMINISTRATIVE PRINCIPLES

The fundamental concepts that guide the DOD were stated some time ago by the Assistant Secretary of Defense (Supply and Logistics), Mr. Thomas P. Pike who, in a departmental memorandum, set forth "some broad principles which are applicable to the administration" of inspection and quality control throughout the Department. He wrote the following:

"1. Inspection and Quality Control policies must encompass all materiel entering supply channels, regardless of whether such materiel is procured from industrial sources, is fabricated at a government facility or is obtained from maintenance, supply and storage activities.

2. The maximum benefits of an Inspection and Quality Control Program cannot be realized unless the various facets of the program, and Inspection and Quality Control's relationship with other activities, are properly coordinated at a high management level.

3. In achieving its primary objective of assuring product quality, Inspection and Quality Control is to be viewed as a constructive activity directed towards the prevention of defects, the detection of unsatisfactory trends, the conservation of material, manpower and equipment, and towards the pooling of meaningful quality data for utilization in design,

maintenance and production, and in supply management.

4. Since the ultimate measure of quality is effectiveness and reliability in service, the accurate and definitive evaluation of product quality necessitates the feed-back of performance quality information to Inspection and Quality Control for appropriate action and for use by other interested activities.

5. The objectives of Inspection and Quality Control are most effectively achieved in collaboration with, rather than by duplication of, other activities within both government and industry. With respect to the latter, maximum utilization must be made of contractors' inspection and quality control information.

6. To be effective, Inspection and Quality Control must be dynamic and, therefore, must incorporate new technologies and new skills in order to keep in synchrony with parallel developments in the fields of design, production, maintenance, and industrial management generally."

The above statements emphasize the "across the board" nature of quality control. Ideally, then, I should discuss quality control plans and procedures pertinent to maintenance, supply and storage, as well as to procurement. But, to prevent this paper from being unwieldy, I will limit myself to plans and procedures in procurement. However, these methods have a wide variety of uses and can be effectively exploited in the other areas.

OBJECTIVES OF PROCUREMENT QUALITY CONTROL

As a logical derivative of its quality control policy, the DOD has established some specific objectives for its procurement quality control program. These objectives are as follows:

A. To assure conformance to contractual requirements.

B. To establish uniform policies and procedures.

C. To obtain assurance economically by:

   1. Elimination of duplication

      a. Among military activities

      b. Between government and industry.

   2. Prevention and prompt detection of defects.

D. To realize maximum government-industry cooperation.

Granted, these objectives are rather "Utopian". However, they do provide a foundation on which military agencies can construct plans, and develop techniques and methods. Actually, these objectives are all facets of a larger objective -- to develop operational plans which

make possible the detection of defects promptly during production and serve as a modus operandi by which government and industry can complement each other's quality control efforts.

QUALITY CONTROL PLANS

Let me briefly mention just three of the several plans which have been developed by the DOD that very nicely implement these objectives. The first is called the Air Force's "Surveillance Plan", the second, the Army Signal Corps' "Reduced Inspection Quality Assurance Plan", and the third is the Department of the Navy's Bureau of Ordnance "Coordinated Industry-Government Acceptance Inspection Plan (CIGAIP)". All of these have a twofold objective; (a) economical inspection, utilizing modern techniques, and (b) the achievement of maximum collaboration between the consumer and the vendor to attain one end -- economic, high-quality production.

AIR FORCE SURVEILLANCE PLAN

For purposes of synopsis, the Air Force plan might be visualized as a structure with three supporting legs. The first is a quality control system specification, MIL-Q-5923B, the seoond is an inspection administration manual, Air Materiel Command Manual 74-1 (AMCM 74-1), and the third is an inspector's handbook, Air Materiel Command Manual 74-21 (AMCM 74-21). The Air Force plan is built upon the concept that it is the responsibility of the contractor not only to deliver a satisfactory product, but also to produce the product under a quality control system satisfactory to the Air Force. MIL-Q-5923B spells out what constitutes a satisfactory system.

It need hardly be said that the Air Force is not inclined to buy a "pig in a poke". It is necessary, then, for the Air Force itself to provide its inspectors with guidelines for performing their duties, generally and specifically, and for evaluating the effectiveness of contractors' quality control systems. AMCM 74-1 does, in fact, tell Air Force inspectors, generally, what their responsibilities and obligations are and how these obligations are to be fulfilled. AMCM 74-21 provides specific directions to Air Force inspectors for evaluating the contractor's quality control system.

In brief then, the Air Force Plan for Procurement Quality Control is built around MIL-Q-5923B -- the contractual instrument by which the government and industry agree that equipment procured by the Air Force must be manufactured under controlled conditions. The Air Force's plan has been very favorably received by industry. It has made possible a high level of cooperation between the government and manufacturers in producing equipment of satisfactory quality on schedule.

SIGNAL CORPS "RIQAP"

The second plan, to which I have already referred, is the "Reduced Inspection Quality Assurance Plan (RIQAP)" of the Department of the Army's Signal Corps. As in the case of the Air Force's Surveillance Plan, the real objective of RIQAP is to achieve the highest possible degree of cooperation between government and industry. Like the Air Force, the Signal Corps attempts to do this in such a way as to

insure that while government and industry complement each other, each operates within its proper orbit of responsibility. In a recent paper, Brigadier General William L. Bayer, USA, Commanding General, Army Signal Corps Supply Agency, summed up the RIQAP as follows:

> "By this plan, we recognize consistent maintenance of high quality on the part of a contractor. When this is true, we place maximum reliance upon the manufacturer's inspection and quality control system and make a drastic reduction in our own physical inspection. To qualify for RIQAP, a contractor must have consistently maintained his quality at a level equal to or better than the Acceptable Quality Level. This quality attainment must not be accidental or haphazard but based upon a sound inspection and quality control system. A vital feature of a sound inspection and quality control system is an effective feedback of data on actual and impending discrepancies with rapid and effective corrective action to prevent them in the future. During installation, we make every effort to dovetail our sampling with the manufacturer's system to make for the maximum in efficiency of operation."

RIQAP is discussed in considerable detail in the Signal Corps "Reduced Inspection Quality Assurance Plan, Sig SIP #3007 (SPL)". This plan, like the Air Force's, has been favorably received in industry and is presently serving the economic and quality interests of both industry and the United States Government. It has been widely recognized as a major step forward in government-industry cooperation.

BUREAU OF ORDNANCE "CIGAIP"

As a result of the DOD's emphasis on "objectivity", "use of contractors' data" and "government-industry cooperation", other organizations within the DOD have also been active in developing plans suited to their specialized objectives. The Bureau of Ordnance, for example, is experimenting with its Coordinated Industry Government Acceptance Inspection Plan (CIGAIP). The following quotation from a Bureau of Ordnance paper indicates the essential nature of this plan:

> "Normal government inspection procedure requires the use of recognized statistical techniques, such as lot-by-lot sampling for evaluation by attributes or variables inspection to establish conformance with the listed characteristics. It is proposed (by CIGAIP) to modify the current requirements for normal inspection and, with the cooperation of the contractor, to use data accumulated during the manufacturing processes (including contractor inspection) to simplify the acceptance inspection program ..... adherence to the maximum extent possible by the contractor to the following recommended practices is essential."

The "essentials" to which the contractor must adhere are; (1) a suitable organization for determining conformance, (2) inspection of Ordnance Classification of Defects (OCD) characteristics, and (3) provision of data assuring that material meets standards and that quality is statistically "in control".

Contractors are expected to employ statistical process-control methods and to maintain processes at or below Acceptable Quality Levels (AQLs) established by the Bureau of Ordnance. When these

conditions are fulfilled by the contractor, the Navy inspector is authorized to adopt decreased inspection if the product quality and production rate are sufficient to meet the qualification criteria. Successful qualification by the contractor permits the Navy inspector to reduce his efforts by intermittent or reduced lot sampling.

These different Army, Navy and Air Force approaches to the solution of the same problem represent considerable aggressiveness and imagination on the part of the quality control personnel of the DOD. At the same time, of course, it must be recognized that the time soon will come when the best elements of each of these plans must be assimilated into one standard quality control plan for the DOD. While the Department encourages fertility of ideas, it is not unaware of the importance of achieving standardization in plans so as to make possible maximum cross-servicing between departments.

METHODS IN QUALITY CONTROL

So far, this paper has been concerned briefly with background policy and with some of the broader plans that already are being used by the departments. Let's now take a look at some of the specific techniques that find widespread use throughout the DOD. I am, of course, making a distinction in this paper between a "plan" and a "method". A "plan", as is evident from the context of these paragraphs, refers to a broad course of action, while the word "method", refers to a particular manner of accomplishing a very specific objective. For example, we can speak properly of a Reduced Quality Assurance Plan which incorporates numerous methods. At the same time, we speak of a "statistical method", for example, attribute sampling as defined in Military Standard 105A (MIL-STD-105A). For purposes of our discussion, we may think of "methods" as classifiable under two headings; (1) engineering, and (2) statistical.

CLASSIFYING DEFECTS

The "engineering" problem is essentially one of determining rationally what quality characteristics of a product should be controlled during manufacturing and inspected after fabrication in order to assure that the design objectives of the item are realized. In a more limited sense, this engineering issue might be called "the classification of defects problem". (Incidentally, the phrase "the classification of defects" is a misnomer. It would be more appropriate to speak of the "classification of quality characteristics".) A Classification of Defects (CD) is nothing more than (1) systematic analysis of each and every characteristic of a product, and (2) a grouping of these characteristics into different categories of importance in accordance with specified criteria.

The DOD has exerted intensive effort in the direction of developing logical and systematic procedures for analyzing the design characteristics of military equipment with a view to identifying those characteristics which most logically should be tested and inspected. Sometimes the problem of classifying defects appears to be academic; one might think that testing and inspection requirements are fully apparent from a review of blueprints. Actually, however, there is a severe limitation in terms of both personnel and instrumentation on the

extent to which inspection and testing can be conducted. Proper planning, then, is of immense technical and economic importance. This subject has also been a matter of particular developmental interest in the Bureau of Ordnance of the Navy Department. A publication, entitled "Ordnance Classification of Defects", published in June 1953, discusses Classification of Defects methods very comprehensively. The DOD, in its publication, Supply and Logistics Handbook, Inspection H105, has made available some basic information with respect to classification of defect methodology.

THE UNIT OF PRODUCT

Three elemental issues confront a quality control engineer who undertakes to prepare a CD. First, he must define the "Unit of Product". This may be a component or part or an assembly. The product may be partially or completely fabricated. The "Unit of Product" is the specific things whose quality characteristics are being evaluated. If the "Unit of Product" is not clearly delineated, it is next to impossible to prepare a CD.

Obviously, when an assembly such as a fire control unit, is to be classified, the quality control engineer has to break down the assembly into numerous "sub-Units of Product" before he can actually classify the quality characteristics. In effect, this constitutes the preparation of an assembly flow chart in which all of the sub-assemblies and parts are properly related to each other. Thus, the groundwork is laid for systematically evaluating the importance of each characteristic of each sub-assembly, part or component, and for properly relating characteristics of different parts so as to prevent unnecessary duplication of inspection. When a product is inspected in-process, there may be numerous sub-units of product, even though there is only one end-item. Such a product may have three separate Classifications of Defects.

MIL-STD-105A defines the "Unit of Product" as follows:

> "The term 'Unit of Product' is the entity of product inspected in order to determine its classification as defective or non-defective. This may be a single article, a pair, a set, a length, an area, a volume, etc., of the finished product or a component thereof. The Unit of Product is established by the government and may or may not be the same as the unit of purchase, supply, production or shipment."

THE EVALUATION OF QUALITY CHARACTERISTICS

Let's assume that the engineer has properly "laid out" the product for which he wishes to prepare a CD. Now he faces the problem of "classifying" each quality characteristic of the various units that make up the end-item.

Essentially, the preparation of a CD necessitates an evaluation of each quality characteristic in terms of the relation of that characteristic to the design objective of the product. The engineer is concerned with projecting what might happen if a particular quality characteristic were "out of tolerance". It is important to note that the engineer is not concerned with the probability of a defect

occurring. He is only concerned with possible consequences in the event that a particular defect should be built into the product. It is beyond the scope of this paper to discuss the further details of how the classification is actually prepared. I am only concerned with indicating that the DOD has given serious attention to developing systematic procedures for preparing CDs and that these procedures are widely used by the Army, Navy and Air Force.

LOT QUALITY

Now let's take a look at the statistical problem. We might call this the "lot quality" problem in contra-distinction to the "unit quality", or "engineering analysis" problem. The issue here is this: How much defectiveness is the quality control or design engineer willing to risk with respect to any particular quality characteristic or group of characteristics? This assumes, of course, that he is willing to accept as axiomatic the fact that he cannot expect perfection. Perfection is something we don't expect to find in this world. Once the quality control engineer accepts this premise, he is in a position to settle for something less than perfection. How much less? Ordinarily, the quality level acceptable to the engineer is a compromise between what he would like to get and what industry is capable of producing. Granted, this is a rather pious statement. After all, it is difficult to fix either of these values with precise quantitative accuracy. It is not easy to say precisely what level of defectiveness can be tolerated. It is not easy to determine what the "average quality" of an industry really is. Such information is frequently unavailable and is quite expensive to obtain. However, over a period of time, various organizations within the DOD have established reasonably accurate estimates of the quality capabilities of industry and, in the light of performance experience, have established quality levels that have proven to be satisfactory to both government and industry. Incidentally, the problem of relating Acceptable Quality Levels to cost is very important and of increasing interest to economists in the DOD.

Now we have discussed two basic elements of quality control methodology -- the Classification of Defects and Acceptable Quality Levels. There are two problems yet to be treated, namely; What sampling plan will be used? What gages or instruments will apply to inspection and testing? I will not discuss this latter matter because it is too wide in scope for treatment here. Generally speaking, however, it is advisable to standardize gaging and instrumentation and to include gaging and instrumentation requirements in a single document, together with the Classification of Defects, Acceptable Quality Levels, and sampling plans.

MIL-STD-105A

At the present time, attribute lot-by-lot inspection is the most widely used sampling procedure for sampling inspection in the DOD. Such sampling inspection is conducted in accordance with MIL-STD-105A. The history, theory and contents of 105A have been discussed in considerable length by many other writers in the field of quality control. I don't think it would serve any purpose to expand further on this subject except to say that during the past year the contents of

MIL-STD-105A have been expanded to provide sampling procedures for expensive testing. On April 27, 1955, the DOD published an appendix to MIL-STD-105A. This Appendix serves the purpose of furnishing a convenient method of applying MIL-STD-105A to characteristics for which relatively small sample sizes are necessitated by the destructiveness, costliness or other aspects of inspection.

SPECIAL METHODS

The subject matter that we have discussed so far might be considered the broad base of plans and procedures in the DOD. At the same time, however, I should like to emphasize that the DOD has a rather large warehouse of procedures that are used for special purposes. For example, multi-level sampling plans by attributes are finding considerable favor. Variables and moving line sampling plans are currently being developed and coordinated within the DOD to take their places with MIL-STD-105A as standard procedures for scientific sampling. In view of the Department's emphasis on government-industry cooperation, it is to be expected that considerable thought has been given to problems of process control. Inasmuch as this paper has been concerned with procurement quality control and since the DOD is a large consumer, this discussion has been restricted largely to problems of acceptance inspection. As a consumer, the DOD is primarily concerned with answering two questions. What is the quality of this material? Should I accept or reject it? However, the Department is not unmindful that from the viewpoint of economics and productivity there is another area of quality control of equal or greater importance than acceptance inspection, namely process control.

The DOD encourages the use of sound process control methods, including, of course, statistical methodology. Particular effort is being focused on the problem of integrating process control techniques with acceptance sampling as a basis for assuring product acceptability. To date, progress in this field has been largely related to reducing acceptance sampling when a particular process control system provides the government with the quality protection it requires. However, there is a strong trend towards making process control systems serve the dual purpose of (a) control of variations during production, and (b) assuring product conformance to government requirements.

STANDARDIZATION

Earlier in this paper I mentioned that one of the objectives of the DOD is to establish uniform policies and procedures. The Department does have a Standardization Program separate from the Quality Control Program by which uniformity in procedures is attained. The broad policies and procedures of standardization are discussed in DOD Directive 4120.3. In general, it can be said that when the design of a product is stabilized, uniform criteria for the acceptance of this product is incorporated into the product specification. These criteria ordinarily include special testing requirements, Classifications of Defects, and sampling procedures.

INSPECTION INTERCHANGE

It is also an objective of the Department to have inspection at any single manufacturing plant conducted by one military agency for

all military organizations. The details of this program hardly come under the subject of "plans and procedures". However, it is worth mentioning that at practically all manufacturing facilities all inspection is conducted by one military inspection service. This is achieved by interchange of inspection services among the military departments. The policies and procedures pertinent to this interchange program are discussed in DOD Directive 4155.3 and DOD Instruction 4155.7.

RESEARCH

As a closing thought, I should like to emphasize that the Department of Defense takes the view that quality control is a "coming field"; but it is not, at present, fully matured as a tool of industrial management. For this reason, the Department is highly research conscious and is encouraging more intensive development in all phases of quality control. Up to the present time, this research has been centered largely on the development of statistical techniques. There is, however, great need for further research in the other areas of quality control, particularly with regard to engineering planning, the economics of price and quality, and in quality control administration. The DOD, in cooperation with industry and with various educational institutions in the United States, is making every effort to assure that quality control administration and methodology keep abreast of new developments in design and production and with the increasingly complex requirements of military logistics.

QUALITY CONTROL STANDARDS IN SHORT RUN PRODUCTION

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Lukens Steel Company

It is my intention to illustrate how control charts can be used to determine process capabilities, set shop tolerance or quality standards, and maintain the quality standards in a job shop operation. Many industries have reported on outstanding results from the estimation of process capabilities using $\bar{X}$ and R charts. This paper discusses the use of $\bar{X}$ and R charts on a process which does not produce the same product for any length of time.

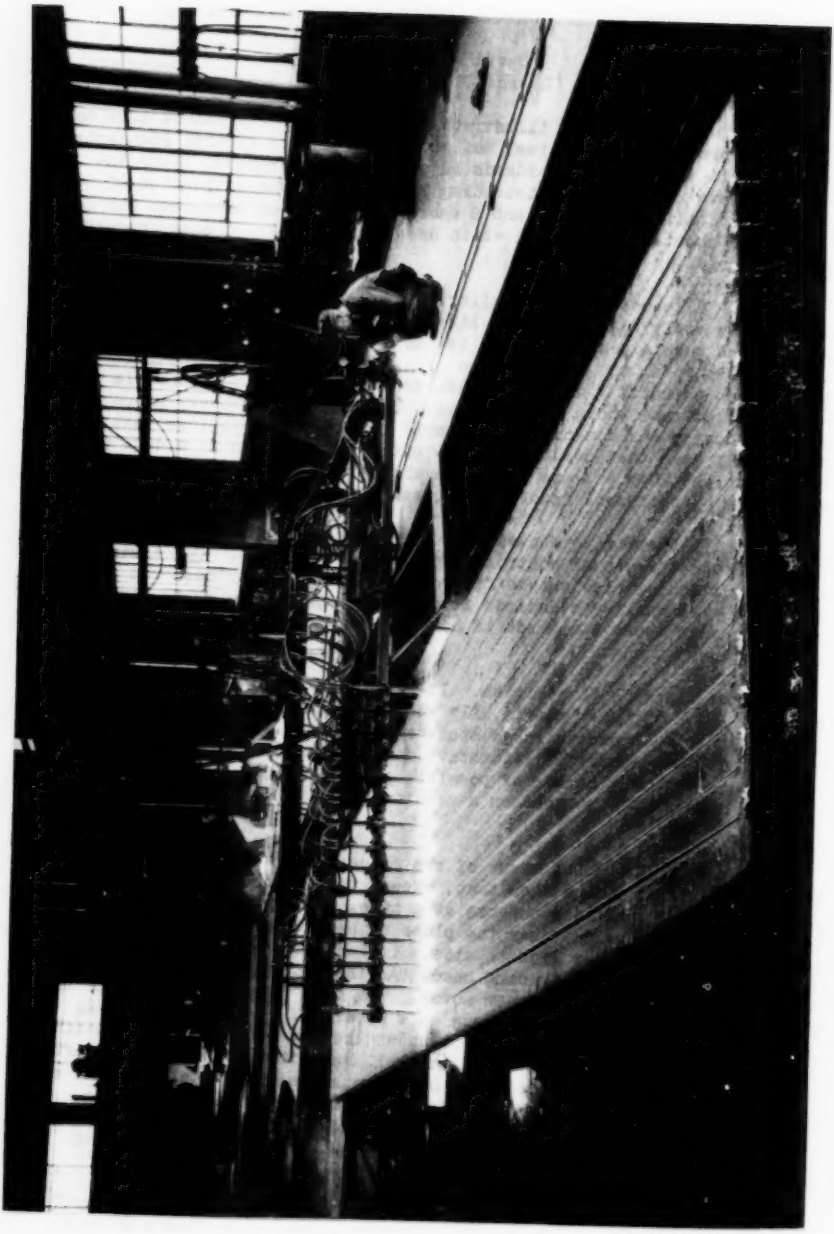
During discussions with quality control people from other companies I have frequently heard comments like this, "We can't use control charts on such and such a job because it is not a mass production type operation". They point out that the use of statistical quality control methods and scientific quality standards are practically impossible because of extreme short run problems. In dealing with heavy gauge steel products, our company is regularly faced with operations that desperately need the advantages to be offered by the use of modern quality control methods but are of such a short run nature as to make difficult the application of usual techniques.

The illustration presented here has enough job shop characteristics to discourage the use of control charts at first glance. Our assignment in this particular case was to find out how well this process was doing, determine what quality standards it could be expected to meet, find a way to improve those standards if needed, and to maintain the conformance to those standards.

Let me describe the process. It is called "Flame Cutting Steel Shapes". Tank sprocket wheels, fly wheels, bearings, bridge expansion joints, lift truck parts, large stone saw blades, eye bars for bridge trusses, and components of locomotive underframes are typical of the practically infinite number of possible products coming from this process. They are produced on a machine called a "Travograph". (See fig. 1)

You are all no doubt aware of the process of cutting steel with a gas flame. This machine does that, except that it does it with anywhere from one to fifteen torches at a time. The torches are mounted on a rigid bar suspended over the plate to be cut. The bar can be moved back and forth or side to side. Its movement is controlled by the operator who uses a tracing head. As the tracing head is moved, every torch attached to the bar moves. The main body of the machine is mounted on tracks, this makes long cuts possible. A plate is laid in on "pots" on one side of this track under the bar supporting the cutting torches. The plate must be level and well supported to avoid any shifting during the cutting operation. On the other side of the tracks is a long steel table or platform on which the operator works. Templates or patterns are laid out on this platform and the operator traces their outline with the tracing head thus causing each torch which is lit to cut out a steel shape closely duplicating the shape of the pattern.

As you can well imagine such a process is highly versatile. In order to point up the job shop problem that exists here, let's consider



A Travograph Fig. 1

the following facts.

1. Order Size - Orders range in size from one piece to several hundred pieces. One piece orders are not nearly so uncommon as one hundred piece orders. An individual order may call for many different shapes. An example of that might be the many differently shaped pieces required for the underframe of a locomotive or the bucket of a large power shovel. In these cases a machine might be required to cut one of some parts, two of another, and twenty of some other.

2. Repetition of Orders - Orders very seldom repeat within a short time. An order might be considered repetitive by this shop if there is a reasonable possibility of cutting it again this year.

3. Length or Duration of Run - As you can see from the type of order processed our runs can be very short. If all the pieces on an order are identical and the shape is simple, the whole thing can be set up, cut, and off the machine in half an hour. We, occasionally, have what we consider a long run when we cut the same thing for several days. Even a full day's cutting on the same shape is rather unusual. Times for cutting one piece can vary from several minutes to several hours.

4. Variety of Product - As you see many different items are made on these machines. Big cantilever beams for bridge construction, heavy flywheels for engines, gear wheels, all sorts of grills and grates, even saw blades, are common items. In thickness of plate from which the item is cut we have ranged from 3/16" to 30". Individual dimensions may vary from less than an inch to over 300". Customer tolerances are both unilateral and bi-lateral.

5. Another variation in the operation of these machines is the manner of tracing. In some cases the operator guides the tracing head over a drawing on paper which is fastened down to the steel platform on which he works. On some jobs, a pattern is traced directly onto the steel table, using soapstone. The operator then traces over the white soapstone lines. In other cases, sets of guides are used, which are followed by a wheel on the bottom of the tracing head. (These are used only for straight cuts.) When cutting circles and holes, a compass-like rig, called a radius rod is fastened to the tracing head. The other end of the radius rod is placed in a pointed swivel which is seated in a center punch mark on the steel table. This allows the head to rotate about that point. Most of the machines are, also, fitted to use an electric eye tracing head. This electric eye follows the edge of a black and white silhouette which is laid out on the steel table and covered with glass. The glass covering is simply to prevent an accumulation of dust.

This then is the operation as we saw it when we were asked to develop a quality control program. The standard texts on quality control covered applications of $\bar{X}$ and R charts on processes which were producing the same item for relatively long periods of time. At first glance there appeared to be no way we could use control chart techniques in developing the quality standards for this job. After some consideration, however, we found a way in which the charts could be applied.

Any particular product coming from these machines might have one or any number of gas cut dimensions. Those dimensions, as we have seen,

were far from uniform. But actually what we were concerned with was not the production of some set of specific dimensions. It was the adherance to any set of specified dimensions. The thing to control in this case was the machine, not the product. We needed to measure how well or how poorly the machine was doing on any specific product dimension. Essentially what we decided to do was to code all of our data, simply by equating the desired dimension to "0". The population from which we were sampling then was not so many items of one product. It was, rather, an infinite population of deviations from specified dimensions for many products.

Let me try to illustrate for you the approach we were taking. Given an order for 50 rectangular pieces, say 12" by 24", we could as easily say we were producing an infinite number of 12" dimensions and of 24" dimensions. If we algebraically subtract 12 from the 12" dimensions and 24 from the 24" dimensions we are now producing twice as many of the same thing --- so many deviations from a nominal dimension. Now it seemed simple. All we had to do was take samples of 5 every so often from this population of deviations and we could make a control chart. But what about the occasion when only one piece was being made. Let's say the one piece is a circle. If we were to measure the diameter in 5 different directions across the circle and subtract the nominal diameter from each of these measurements we again have the same thing as in the case of the rectangles --- a sample from a population of deviations.

At this point a slight technicality of control charts might be raised. Technically, a control chart sub-group should consist of some number of consecutively produced items. In this case our items were deviations from nominal dimensions. How is it possible to select consecutively produced deviations from nominal. We chose to ignore this slight discrepancy. In fact, we felt that we could sample the same dimension in 5 different places on one piece, and in the next case select the same dimension on 5 different pieces. With respect to the product being produced our range in some cases would be an estimate of with-in piece variation, and in other cases would be an estimate of the piece to piece variation. Had we been concerned with controlling some product variation within some specific tolerances, this of course would not have been done. We were, as I have said, concerned with determining the capabilities of these machines.

While there may be some argument with the method of sub-grouping outlined above, it got results. An earlier attempt without control charts to develop process capabilities and establish standards on these machines had not been successful in the sense that operating personnel did not believe the results or use them. Let us proceed to examine some of the problems of a practical nature which came up during this survey.

Inspectors in this area performed one operating function in that they deburred or removed slight amount of slag formed during gas-cutting from the pieces as they inspected them.

The inspectors did not perform their inspection at the machines. The pieces are lifted by crane magnet and moved to an inspection station. This movement results in a loss of identity as to order of production. If two machines happen to be cutting the same piece, the identity with respect to machine was also lost. These same inspectors were not accus-

tomed to recording dimensions, while they actually measured the pieces, the measurement was used in a go-no-go sense. Little or no information was fed back to the operator concerning the dimensional quality of the pieces he cut.

Generally speaking these conditions did not seem extremely favorable to the use of control charts. Another consideration which we felt was needed before actually gathering data, was a listing of the factors which might cause variation from the specified size. Some of these factors were:

1. The accuracy of the template from which the piece was being cut.
2. The state of repair of the machine.
3. The size and condition of the tips on the torches.
4. The absolute size of the dimensions being cut.
5. The general shape of the pieces being cut.
6. The gauge of the plate from which the pieces were being cut.
7. How well the pieces were supported during the cutting operation.
8. The location of a specific piece on a plate, i.e., a piece being cut from the center of a plate might have less possibility of movement during cutting than one located toward the edge of the plate.
9. The method of tracing (electric eye, mechanical, manual).

Other factors such as crane and building vibration could not be anticipated. Some of the plates processed in these buildings weigh as much as 15 or 16 tons. When such a plate is dropped accidentally near one of our machines, even if only a few inches, the building is inclined to shake.

At this point, knowing some of the things to expect, we decided to commence gathering data. While there were nine travographs in the shop it had been decided that our initial survey would be restricted to three of them. The data gathered on these three machines was to be analyzed as fully as possible before looking at the other machines.

Because of the strangeness of control charts to our personnel and because at this point we were interested only in finding out how well the process was doing, we decided not to post the charts at the machines. A form which gave us the information necessary to control charts, without the calculations or graphs, was used to gather the data. Initially the inspectors were asked to visit the machines at least once each two hours and select four pieces, measure them and record the dimensions on this control chart data sheet. Almost immediately the question of what dimensions to select or measure came up. We found that in many instances there were differences of opinion between the operator and the inspector as to what dimensions were critical, which was a point of view we had not anticipated. The solution to this problem came in the fact that all drawings and templates, and the order which was placed at the machine came through the template drawing room. We asked the supervisor of the template drawing room to indicate a dimension on the template prior to sending it to the machine. This took the mental strain of decision making away from the shop personnel. At this point a set of instructions were issued to all personnel in the shop so that they would know the purpose of the survey, and their responsibilities in it. Almost immediately we found that the inspectors were having trouble keeping up with the work. Since they normally worked at inspection stations where

Fig. 2

Lukens By-Products Division
Dimensional Variation in Gas Cutting
Machine Number 3 - Manual Cutting

Dimension	Tally	Totals
+15/32 (one + 29/32)	///	3
+14/32		
+13/32		
+12/32	//// /	6
+11/32		
+10/32		
+ 9/32	/	1
+ 8/32	//// //// /	11
+ 7/32	/	1
+ 6/32	//// //// //// //// //// //	32
+ 5/32	//// //// ///	13
+ 4/32	//// //// //// //// //// //// //// //// //// //// //// //// //// //// //// //// //// //// //// /	96
+ 3/32	//// //// //// ///	18
+ 2/32	//// //// //// //// //// //// //// //// //// //// //// ////	60
+ 1/32	//// //// //// //// //// //// //// //// ////	29
Nominal	//// //// //// //// //// //// //// //// ////	29
- 1/32	//// //// ///	8
- 2/32	//// //// //// //// //// //// //// //// //// //// //// /	21
- 3/32	//// ///	4
- 4/32	//// //// //// //// //// //// //// //// ////	9
- 5/32		
- 6/32		
- 7/32		
- 8/32 (- 28/32 one) (- 31/32 one)		

KEW & DMK: October 6, 1953

the finished work was brought to them, the practice of visiting machines upset their routine and disrupted the flow of work. We looked around for someone else to do the job. It proved to be a happy circumstance that there was a position in the shop just made to order for us. Each three machines were serviced by a machine checker. His job consisted of getting material moved to the machines and getting the drawings, orders and templates to the machine. He, also, made a casual check of the first piece cut. There was ample time in this job to handle the sampling and recording of measurements.

Another factor which arose very early was the heat of gas cutting. Pieces immediately after cutting were hot. There was just enough heat in a long piece to notice a difference between the measurements taken after the piece cooled. It was decided that the checker would select his sample and allow it to cool before measuring it.

After the usual trials and tribulations of data gathering were experienced we got about two weeks worth of data. Let's see what our data showed. Shown in Fig. 2 are frequency distributions made from the individual measurements. Nominal indicates the required dimension, whatever it might have been. As you can see, there was considerable spread. Also, you might note the irregularity of form, in that there is a dip at each odd number of 32nds. Our checkers had been used to measuring only an occasional piece to check whether or not the piece fell within tolerances. They tended to measure to the closest 1/16" rather than 1/32".

A smooth frequency curve developed from the frequency distribution would make obvious the tendency to cut on the large size.

Going back now and looking at some of the items we suspected might affect the variation in this process we made some analyses simply by making frequency distributions of the individual measurements.

Distributions were made by various classes of length of cut. Little or no difference showed up. The same process was followed for gauge. A small difference was noticeable here. Shape did not seem to matter. There was a real difference between I.D.s and O.D.s when we were cutting rings. This stemmed from the usual shop philosophy that a big piece could be made smaller but a small piece could not be made larger. Electric eye tracing proved only a little better than manual tracing. Frequency distributions arranged by templates showed outstanding difference, however. Two factors then seemed to be really important. (see Fig. 3) Template accuracy and the tendency of operators to play it safe and cut large. We felt that if these two items were controlled the total variation would be materially reduced and almost all cutting would be within plus or minus 1/8". Relating this possibility to the usual customer tolerances we did not feel that more than this would be needed.

Our first report included the chart in Fig. 4 which shows the proportions of product by machines conforming to the arbitrary standard of ±1/8". The recommendations made were as follows:

1. Review and revise all electric eye templates to bring cutting closer to the center line.
2. Review and revise all manual templates to bring cutting closer to the center line.

PLANT #4 GAS CUTTING
Variation from nominal in 32nd of inch by templates

Fig. 3

Order No.	690019 and 700012							
Mark No.	2		5		8		11	
Dimension	37-1/2"	15"	24"	6-5/8"	24"	14-3/4"	7-7/8"	5-1/8"
Variation in 32nd of Inch: 8								
7								
6								
5								
4								
3								
2								
1								
0								
-1								
-2								
-3								
-4								
-5								

Fig. 4

SUMMARY OF STATISTICAL STUDY OF

THE VARIATION IN GAS CUTTING OF

TRAVOGRAPHS #2, #3, & #4

Travograph	Type of Cutting	Process Center *	Variation **	Estimated % of Pieces within ±1/8"
4	Electric Eye	+.058"	±.108	96.9%
3	Manual Tracing	+.089"	±.180	72.6%
2	Manual Tracing	+.092"	±.117	80.2%

* Average of individual measurements in inches from nominal.

** Variation of individual pieces in inches from average to be expected from present processes.

3. Establish control charts on each machine based on the deviation from specified plus 1/2 the tolerance. The latter was to keep our aim in the middle when the tolerance was unilateral.

As a result of these recommendations templates were revised as used. A log was kept by the template room of all changes made. When changes were made we followed up by checking the pieces produced for undersize dimensions.

We then started the process of switching over to control charts. Forms were made up and samples and instructions were drawn up. Several sessions were scheduled with the shop foremen, the machine operators, and the machine checkers to go over the method of making control charts. Three chip sets were used to demonstrate the making and use of charts. We had the carpenters put up large glass covered holders at each machine. When we felt we had covered every item we started off. The initial samples on each chart were taken by me. I went thru each step with each checker. Then I watched him do it several times. I helped him correct his errors. When the points were out of control we made a note right on the chart. For the first week or so I worked part of every turn - this shop works around the clock. Then I felt each man had the hang of it. I was wrong. As soon as we left the shop, ranges and averages were incorrectly computed. A quality control analyst and myself began making daily trips to see each checker and correct the errors he made on the preceeding turn.

It took continual attention to get the foremen to look at out of control points. Eventually, however, the operators began noticing that the charts showed up bad about the same time he thought something had gone wrong. The operators started questioning me as I walked thru the shop. We talked of how this statistics stuff was the same as odds in poker and dice. Gradually it caught on. The operators asked the foreman about the points they could not explaing. Fig. 5 is an example of a chart made by the checkers in the shop.

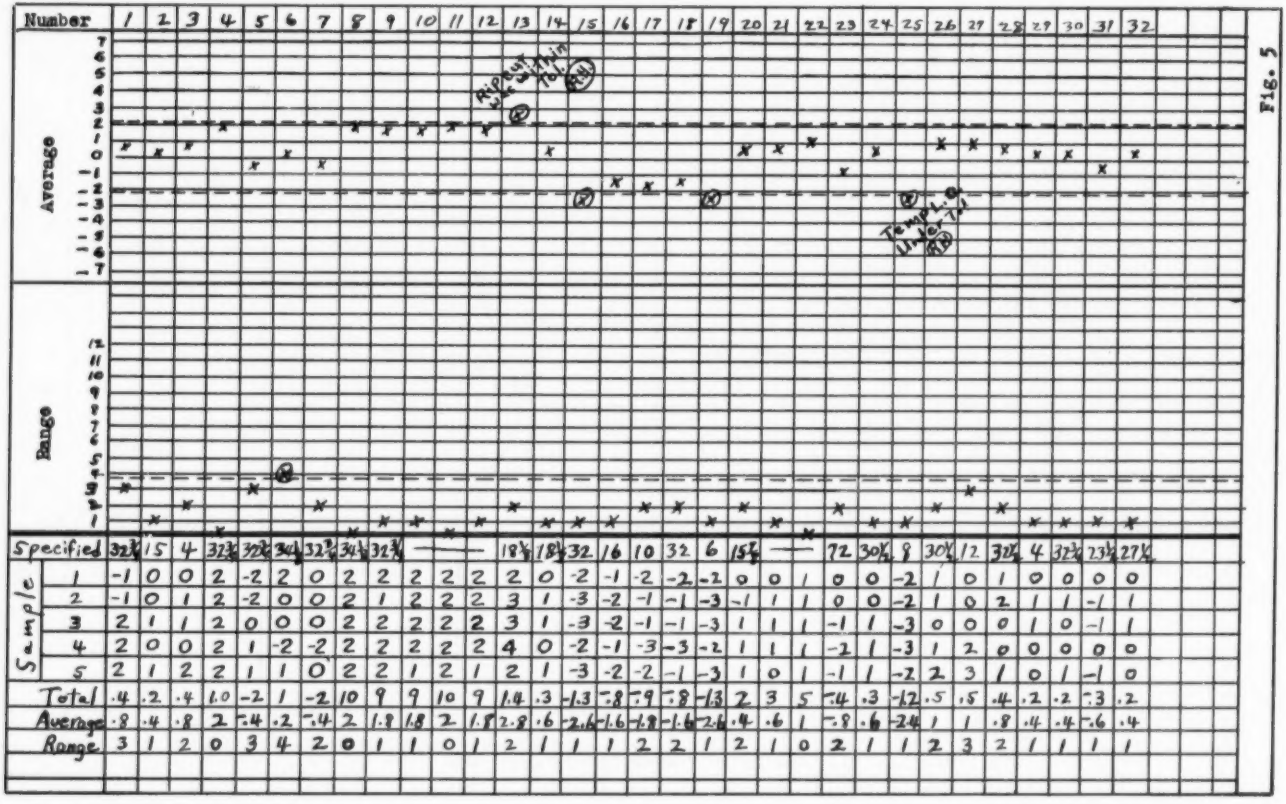
The charts were started in October on three machines, in December we reported again. Fig. 6 are the comparisons that were made.

As a result charts were set up on the remaining machines. Limits were set at $\pm 1/8"$ and this became the accepted tolerance standard for this operation.

We then developed a method of periodically reporting to management. These reports show the proportion of the total production conforming to standards in each of the past six months. For the current month they show a distribution of each machine's production with respect to the standards.

Later a procedure book was drawn up and issued to those concerned. It has been revised once, simply to be more explicit. Copies of the pertinent pages are hung at each machine. This is required because lay offs and increases in personnel cause shifting of personnel in the machine checkers job.

Upon several occasions it has been necessary to remind the foremen that interest in the control charts can be maintained only if they check out of control points. When they let this job slip, the propor-



Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Specified	32½	15	4	32½	32½	34½	32½	34½	32½	—	—	—	18½	18½	32	16	10	32	6	15½	—	—	72	30½	8	30½	12	31½	4	32½	23½	27½
Sample 1	-1	0	0	2	-2	2	0	2	2	2	2	2	2	0	-2	-1	-2	-2	-2	0	0	1	0	0	-2	1	0	1	0	0	0	0
2	-1	0	1	2	-2	0	0	2	1	2	2	2	3	1	-3	-2	-1	-1	-3	-1	1	1	0	0	-2	1	0	2	1	1	-1	1
3	2	1	1	2	0	0	0	2	2	2	2	2	3	1	-3	-2	-1	-1	-3	1	1	1	-1	1	-3	0	0	0	1	0	-1	1
4	2	0	0	2	1	-2	-2	2	2	2	2	2	4	0	-2	-1	-3	-3	-2	1	1	1	-2	1	-3	1	2	0	0	0	0	0
5	2	1	2	2	1	1	0	2	2	1	2	1	2	1	-3	-2	-2	-1	-3	1	0	1	-1	1	-2	2	3	1	0	1	-1	0
Total	.4	.2	.4	1.0	-.2	1	-.2	1.0	.9	.9	1.0	.9	1.4	.3	-1.3	-.8	-.9	-.8	-1.3	.2	.3	.5	-.4	.3	-1.2	.5	.5	.4	.2	.2	-.3	.2
Average	.8	.4	.8	2	-.4	.2	-.4	2	1.8	1.8	2	1.8	2.8	.6	-2.6	-1.6	-1.8	-1.6	-2.6	.4	.6	1	-.8	.6	-2.4	1	1	.8	.4	.4	-.6	.4
Range	3	1	2	0	3	4	2	0	1	1	0	1	2	1	1	1	2	2	1	2	1	0	2	1	1	2	3	2	1	1	1	1

Fig. 5

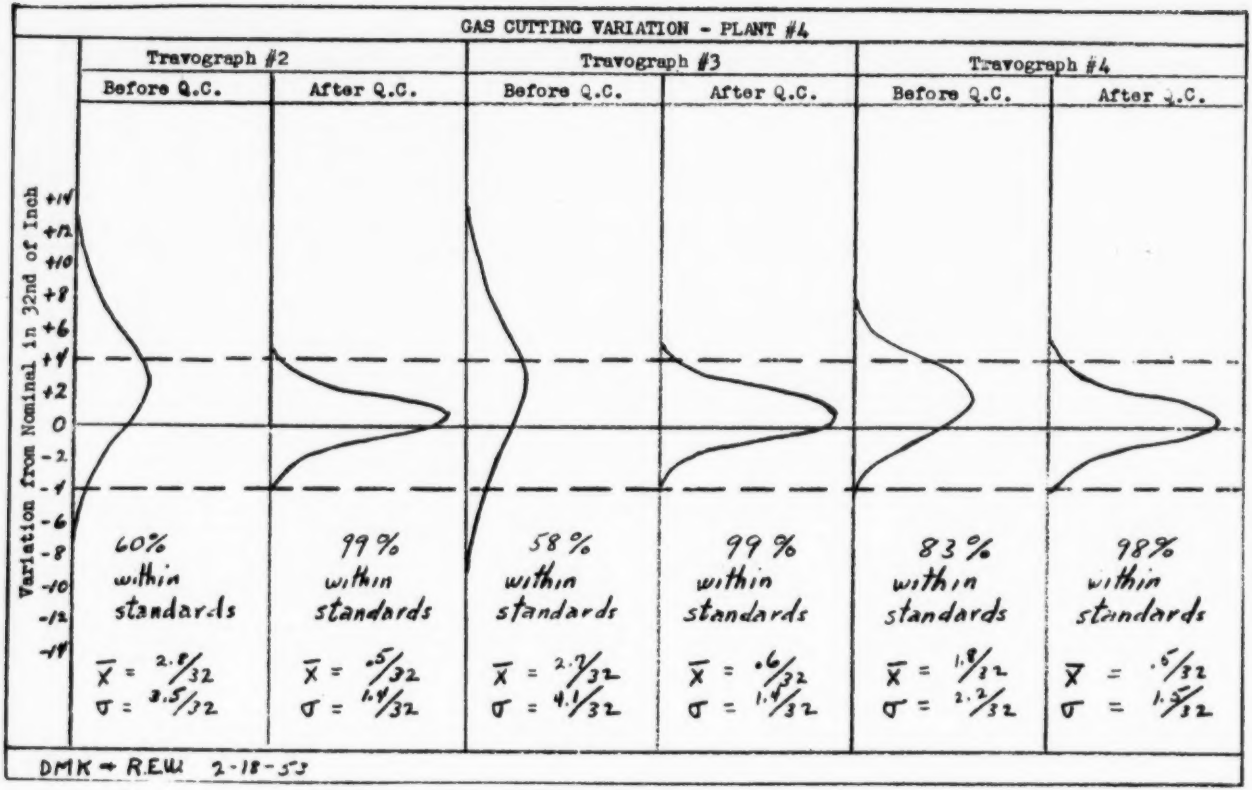

GAS CUTTING VARIATION - PLANT #4
Travograph #2
Before Q.C.
After Q.C.
Travograph #3
Before Q.C.
After Q.C.
Travograph #4
Before Q.C.
After Q.C.
Variation from Nominal in 32nd of Inch
+14
+12
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
-10
-12
-14
60% within standards
$\bar{X} = 2.8/32$
$\sigma = 3.5/32$
99% within standards
$\bar{X} = .5/32$
$\sigma = 1.4/32$
58% within standards
$\bar{X} = 2.7/32$
$\sigma = 4.1/32$
99% within standards
$\bar{X} = .6/32$
$\sigma = 1.4/32$
83% within standards
$\bar{X} = 1.8/32$
$\sigma = 2.2/32$
98% within standards
$\bar{X} = .6/32$
$\sigma = 1.5/32$
DMK → REW 2-18-53

Fig. 6

tion of pieces within plus or minus 1/8", the new standard shop tolerance, goes down.

What did we gain?

1. Reduction in customer complaints for dimensional errors.
2. Reduction in back charges from our other divisions who use these products.
3. Reduction of rework in one other division.
4. The setting of shop standards by this method is progressing in other areas of our company. In this and other areas such standards have proved valuable to our sales department and have helped us reduce estimates and machining costs.

What was the cost?

No additional personnel in the shop. The control has run since October 1953 with less than ten hours attention a month on the part of the quality control department.

IMPROVED QUALITY CONTROL THRU PERFORMANCE MEASUREMENTS & EFFECTIVE CORRECTIVE ACTION

R. L. Grunewald
General Electric Company

Introduction

. . . Looking for an effective, hard hitting approach to your manufacturing loss and quality problems? . . . If so, this paper should interest you since it describes the system which has become a "way of life" with a group of practical operating people.

This system has been very successful in reducing the costs of quality in the Components Manufacturing areas at Evendale, Ohio. Within the first nine months of coverage four major manufacturing areas showed a combined manufacturing loss reduction of approximately 75 percent, and a decrease in percent defective of approximately 85 percent.

This system, known as the Master Quality Control System, embraces several fundamental concepts of a successful business operation --

(1) Planning to cope with a recognized problem.

(2) Organizing to implement the plan of action.

(3) Integrating efforts of all affected functions toward a common goal.

(4) Measuring performance of individuals and units.

(5) Recognizing individuals and units for their performance.

Perhaps the most novel approach developed in this system is that of effectively, efficiently, and continuously recognizing the performance of individuals, as well as that of units, through measurements against standards which the individuals themselves have established. The system provides the means for quality improvement with a minimum expenditure of time and money. Integration of effort is a distinctive feature of the system, without it poor results are obtained. It must be recognized that this paper can only serve as a guide in connection with other installations, since each manufacturing operation must be analyzed separately to determine its needs. There is no universal system that will cover all manufacturing areas.

1. Planning to Cope With Problem

Because production quantities of jet engine components are relatively small, and the continuing search for better engines results in almost constant changes, the manufacture of these components presents a challenge to those responsible for the economical control of their quality. Extremely close tolerances on large flexible parts, introduction of new materials such as titanium, and new and more difficult processes on both old and new materials, are just a few of the many problems confronting manufacturing. The controls on these materials and processes had to be exercised during the manufacture of the product rather than after,

because of high product cost and lengthy cycle time. Our objective, then, was the development of a quality control system that would be flexible, yet provide the detailed data necessary to bring about specific improvement. We adopted the "Master Quality Control System" as our solution. (This system combines and pyramids attribute data from an individual work station to a composite of all operations. An average quality level is used as a standard at each level of measurement, and the "pyramiding" begins with the operator and ends with the section manager.)

A "system instruction" was our next step; however, certain information relative to the inspection and manufacturing functions had to be obtained, analyzed and altered before the instruction could be prepared.

Topics covered under manufacturing were:

(a) Lot size
(b) Flow between work stations
(c) Cost of product
(d) Operation sheets
(e) Production Control System
(f) Cycle time
(g) Type of manufacture

Topics covered under inspection were:

(a) Types of records in use
(b) Inspection frequency
(c) Corrective Action procedure
(d) Operation sheets
(e) Type of inspection
(f) Inspection controls
(g) Type of inspection equipment

Equipped with applicable manufacturing and inspection procedures and reports in the initial area to be covered, the "system instruction" was formulated. This "instruction" contained everything necessary to effect a flow of usable inspection data to Quality Control Engineering on a daily basis.

It covered the activity of those directly associated with the manufacture and movement of parts as indicated below:

A. Manufacturing

1. Adherence to operation sheets (methods and specifications)
2. Responsibility for quality
3. Identification of work

B. Production Control

1. Control of work authorizations (identity of work to operator)
2. Control of work assignments
3. Control of inspection priority

C. Inspection

1. Proper completion of inspection records

2. Inspection to operation sheets
3. Use of work authorization cards

An explanation of "the system" was given to each person involved, in order that he would not only know his own role in the program, but also would be familiar with the roles of others. In this way, everyone related his own position to that of the others, and could see that only through cooperation could the common goal be achieved.

2. Organizing To Implement The Plan

In order to inaugurate "the system", the Superintendent of the area being studied, called a meeting of the involved members of his staff. The General Foreman, Production Supervisor, Planning Supervisor, Inspection Supervisor, and Quality Control Engineer were present. All pertinent facts were discussed at this meeting and when agreement with the proposal was attained, plans were made for the installation. The General Foreman was given the responsibility for setting up meetings with his foremen and having them set up meetings with their operators, to explain "the system" and the part each individual was to play in it. A representative of Quality Control Engineering was present at these meetings. (The importance of these meetings cannot be over emphasized; they not only served for purposes of instruction, but also presented an opportunity "to sell" the system to the operators.)

Meetings were held with foremen of inspection and inspectors before entry into the area. The importance of accurate records and the proper use of forms were covered in detail.

3. Implementation Of The Plan

The time required for gathering data prior to posting initial control charts depends on two things: (1) the authenticity of the data, and

IN-PROCESS INSPECTION RECORD

Date 8/3/55 Area AAA Insp. Johnson

Drawing Number	Op'n. No.	Lot No.	Def. Pcs.	Def. Char. (Itemized) Ser. Nos. & Remarks	Area Code	Operator's Badge No.	Pcs./ Oper.	Char./ Pc.
1250369	23	102	0		ABC	11835	20	21
3240862	10	120	22	.620 - .640 cks. .645 (20 pcs) LD 900-919 3.124 - 3.126 cks. 3.121 (20 pcs) LD 902-921	ABC	6840	25	12
6738222	38	96	1	1.000 - 1.001 cks. 1.003 LD 875	ABC	20630	24	18

Chart 1

(2) the number of characteristics generated per operator. There is no steadfast rule governing the minimum number of characteristics, but we found that data collected over a month's time is sufficient for most operations. (Accordingly, new percent defectives are computed monthly for all individuals and problems, so that changes can be incorporated in the control limits.)

Data was submitted by inspectors on an Inspection Record similar to Chart 1.

After sufficient data was collected, a characteristic percent defective was computed for each operator. (Throughout this paper all references to percent defective pertain to a ratio of characteristics produced out of specifications, over the total characteristics produced. A characteristic may be a dimension, a surface finish, a hardness requirement, etc.) We decided to use 99% limits for control purposes. The Number Defective Tables issued by the Statistical Methods Section, General Engineering Laboratory, Schenectady, New York, was employed as an aid in determining out of control points.

4. Measuring and Recognizing - The "System" In Operation

As this paper develops, it will be clear that the quality performance of all levels of supervision are affected by the work of operators. In the example shown on the Foreman's Summary Sheet (Chart 2), Operator

FOREMAN'S SUMMARY SHEET

Green
Red

Foreman Jones Area AAA G.F. Jackson Mo. Aug.

Operator	Date	1	2	3	4	5	6	31	Total	New $\bar{P}$
6840 Riley	Def.	0	2	40	0	1				
$\bar{P}$= .8	Prod.	200	365	300	420	990				
11835 Miller	Def.	5	1	0	0	2				
$\bar{P}$= 1.6	Prod.	200	365	420	205	850				
20630 Dawson	Def.	3	0	1	0	1				
$\bar{P}$= 1.1	Prod.	562	498	432	202	892				
	Def.									
$\bar{P}$=	Prod.									
Totals		10	4	49	0	5				
$\bar{P}$= 1.0		2000	2500	2065	1200	3000				

Chart 2

Riley, badge number 6840, caused a red square to appear on his foreman's sheet on August 3rd, indicating defects in excess of those permitted by the Number Defective Table. A red square is an action signal, and a foreman must take immediate action to correct the underlying cause of the red square. Green squares, indicating fewer defects than those defined by the "Number Defective Table", denote progress, but since improvement is expected, we would expect to see green squares. Individuals having a red or green square on their control charts have significantly deviated from past performances. Entries are made daily on the Foreman's Summary Sheet from the Inspection Record. An entry consists of defective characteristics over total characteristics for each operator. (To make the system more effective, the foreman's sheet is kept in plain view of all the operators.)

The foreman of Manufacturing has an added incentive to improve his operation because his activities are charted daily in the General Foreman's Office. (See Chart 3)

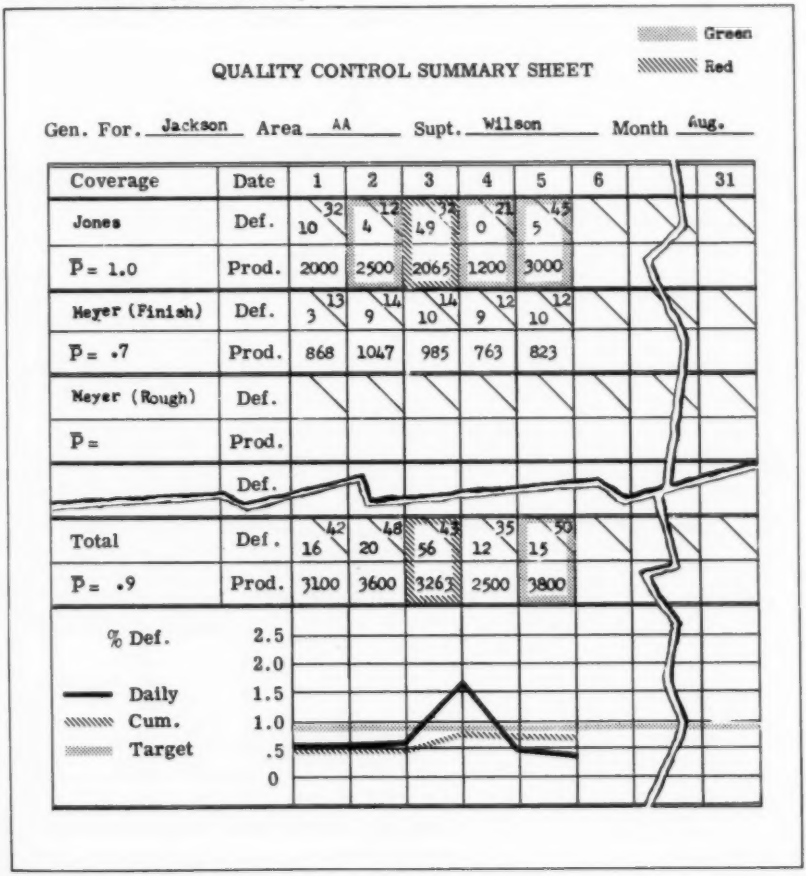


Chart 3

A comparison of Charts 2 and 3 show how the defects and characteristics from the Foreman's Summary Sheet are totaled and carried forward to the General Foreman's Sheet. Control limits are computed as before, using the operator's past performances as the basis for computation. Note that Operator Riley not only caused his foreman, Jones, to have a red square, but was responsible for General Foreman Jackson having a red square. The foreman soon realizes that he must induce his operators to do good work if he is to avoid unfavorable measurements.

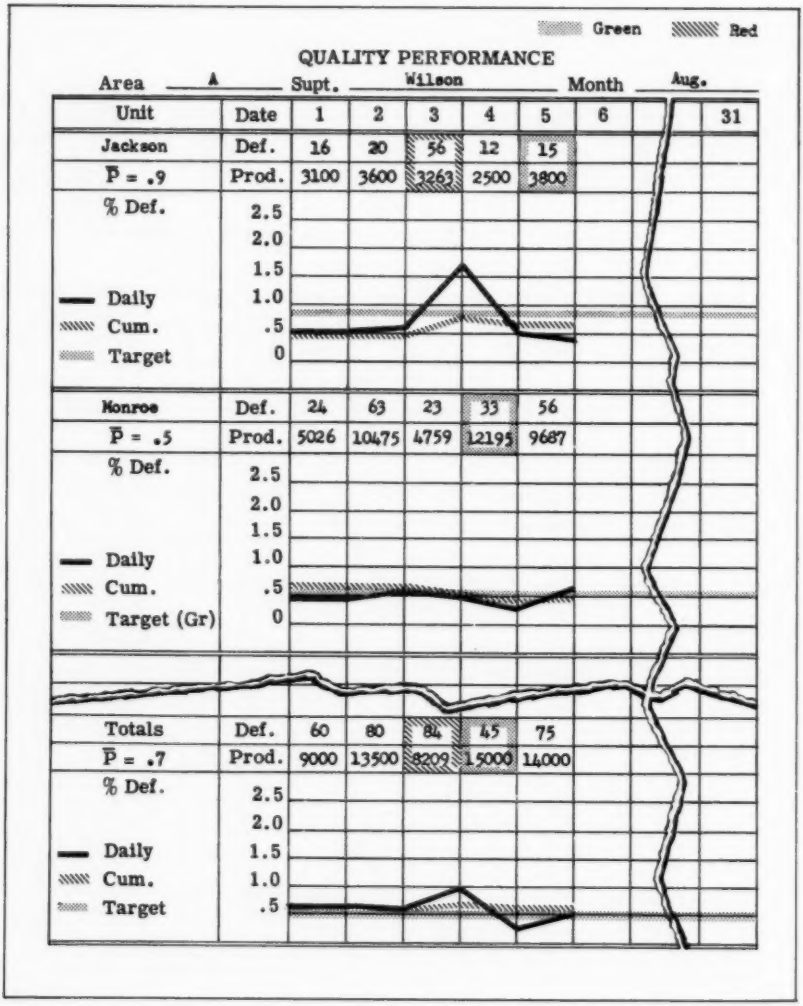


Chart 4

The figure above the diagonal lines represents the point that determines an out of control condition, and is supplied the General Foreman so that he may take preventative measures. Defects at, or in excess of, this number warrant a red square. The posting of this figure permits the General Foreman to see how badly he is out of control, or if he is on the verge of going out of control. The trend chart at the bottom of the General Foreman's Sheet shows the daily percent defective, the cumulative percent defective, and the target percent defective for the entire area.

The Superintendent uses a chart identical to Chart 3 to measure his General Foreman, thereby also being in a position to appraise the quality activity of each foreman.

The final step in this "pyramiding" system of measurements concerns the Manager of Manufacturing. His summary sheets enable him to measure his superintendents and one level under them. (See Chart 4)

To demonstrate the "pyramiding" action we have described, let us take a look at a chart showing how an operator causes a superintendent to be out of control. If the red square were removed from Chart 5 at the

ACTION CHART

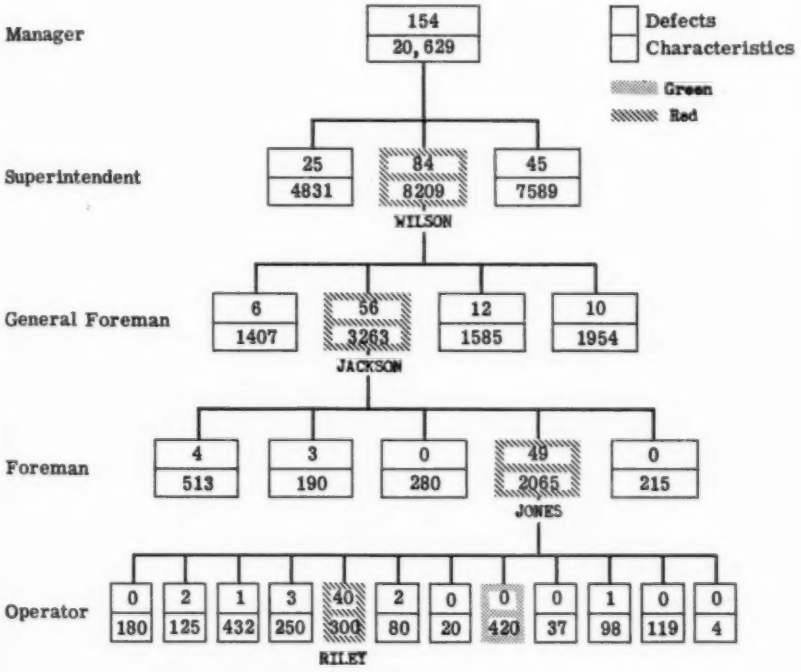


Chart 5

"operator" level, Foreman Jones, General Foreman Jackson, and Superintendent Wilson would not be out of control. Therefore, the chain of red squares can be attributed to the work of Operator Riley. Think of it! Here is a system so sensitive that an operator on the floor causes a Superintendent to take immediate action. Yet, that Superintendent finds that he spends less time on quality problems, because only the significant problems reach him.

This system forms the basis for the actual quality performance appraisal of all levels of Manufacturing personnel under the Section Manager. It plays an important part in promotions and salary increases.

5. Corrective Action

To assist the foreman of Manufacturing in his job of taking action when red squares occur, Quality Control Engineering issues a Corrective Action Request (Chart 6) which explains in detail the discrepancies caus-

QUALITY CONTROL ENGINEERING CORRECTIVE ACTION REPORT

To Jones Code AAA Issued 8/3/55 Due 8/5/55

Operator	Drawing No.	Op'n.	Ser. No./Lot No.	Pcs.
Riley	3290862	10	120	20
Discrepancy .620 - .640 Radius cks. .645 on Ser. Nos. 900-919				
Cause & Remedy This dimension is beyond the operator's control as it is put on with a radius tool. D. Simms of planning is going to have all radius tools checked on a comparator by 8/8/55. This defect will not occur after this date.				
Operator	Drawing No.	Op'n.	Ser. No./Lot No.	Pcs.
Riley	3290862	10	120	20
Discrepancy 3.124 - 3.126 O.D. cks. 3.121 on Ser. Nos. 902-921				
Cause & Remedy Operator error. Operator cautioned by foreman that recurrance of defects could mean removal from job. Conversation report written.				
H. K. Jones	J. B. Jackson		8/4/55	
(Foreman)	(General Foreman)		(Date)	

Chart 6

ing the red squares. This request must be answered within 48 hours, and must be approved by the General Foreman before it is returned to Quality Control Engineering. (These Corrective Action Requests are in "snap-out" booklet form, and approved, completed copies are given to the General Foreman, the Inspection Supervisor, and the Superintendent.) A foreman cannot say that the problem is not his because it involves Planning or some other function. If the solution to the problem requires action by a supporting function, the foreman obtains it immediately. If immediate action is impossible, the foreman must have the supporting function give him a written commitment defining the action to be taken and the date it is to become effective. If Manufacturing and its supporting functions cannot resolve the problem, Quality Control Engineering may assist by running special studies.

6. Analysis Of Problems Within Control Limits

It is recognized that since operators are measured daily on all of the characteristics they generate, it is possible to have one dimension continuously out of specification without causing the operator to have a red square. The Dimensional Discrepancy Record (Chart 7) provides a solution to this problem. Postings are made on this record daily and when

DIMENSIONAL DISCREPANCY RECORD

Part No. 329D862 Op. No. 10

Char. Insp. Radius				Char. Insp. O.D.				Char. Insp.			
Upper Spec. .640		Lower Spec. .520		Upper Spec. 3.126		Lower Spec. 3.124		Upper Spec.		Lower Spec.	
Crit.	Maj.	~~Min.~~	I.P.	Crit.	~~Maj.~~	Min.	I.P.	Crit.	Maj.	Min.	I.P.
Ser. No.	Dim.	Date	Op.	Ser. No.	Dim.	Date	Op.	Ser. No.	Dim.	Date	Op.
900	+.005	8/3	1	902	-.003	8/3	1				
901	"	"	1	903	"	"	1				
902	"	"	1	904	"	"	1				
903	"	"	1	905	"	"	1				
904	"	"	1	906	"	"	1				
1. - Oper. No. 6840				3. - Oper. No.				5. - Oper. No.			
2. - Oper. No.				4. - Oper. No.				6. - Oper. No.			

Chart 7

it is noted that a particular dimension has been violated too frequently, a Corrective Action Request is issued to Manufacturing. The same rules govern this request as outlined before. When a Corrective Action Request is issued, a notation is made on the Dimensional Discrepancy Record and

effectiveness of the answer is checked by watching future entries on the dimension in question.

The Dimensional Discrepancy Record gives a complete discrepancy history of all parts manufactured. If discrepancy information is needed on a dimension or part, this record contains the quantity, severity, dates run, serial numbers, operator, and corrective action taken.

7. Month End Analysis

In addition to the previously mentioned techniques, a complete analysis of each area is made at the end of the month's activity. The General Foreman is provided a list of operators who are performing unsatisfactorily, and he is alerted if any foremen fail to show improvement or other special problems persist. So that management can see the proportion of defects for which each supporting function is accountable, a breakdown of significant defects is also provided.

8. Quality Control Engineering

If the described system is to function properly, the group responsible for its successful installation, maintenance, and refinement must function properly. Quality Control Engineering personnel must have a working knowledge of industrial statistical quality control, and also be adept in dealing with all phases of activities related to manufacturing. They detect problems, assign responsibility for their solution, and follow through to insure effective results. To do this they must be technically competent and versatile.

Through knowledge of machines and process capabilities, the Quality Control Engineer is instrumental in assisting the Production Engineer in his job of providing Manufacturing with practical specifications.

The accomplishments of this Quality Control System are proportional to the degree of effective relationships between Quality Control Engineering and the other functions involved.

9. Results

The remainder of this paper describes some of the improvements which the Master Quality Control System has been instrumental in achieving. These improvements contribute to better customer relations and a more desirable competitive position. Examples of these contributions are --

1. A Continued and permanent reduction in total manufacturing losses within a relatively short period of time. (See Chart 8). This chart represents the actual manufacturing losses in the gear, turbine wheel, compressor rear frame, forward frame, and gear box areas -- a very good cross section of manufacturing activities since small parts, large parts, sheet metal parts, and castings are involved.

2. A tremendous improvement in the quality of the part submitted for inspection (See Chart 9) This chart covers the same areas and times as Chart 8, and depicts the actual percent defective of these combined areas.

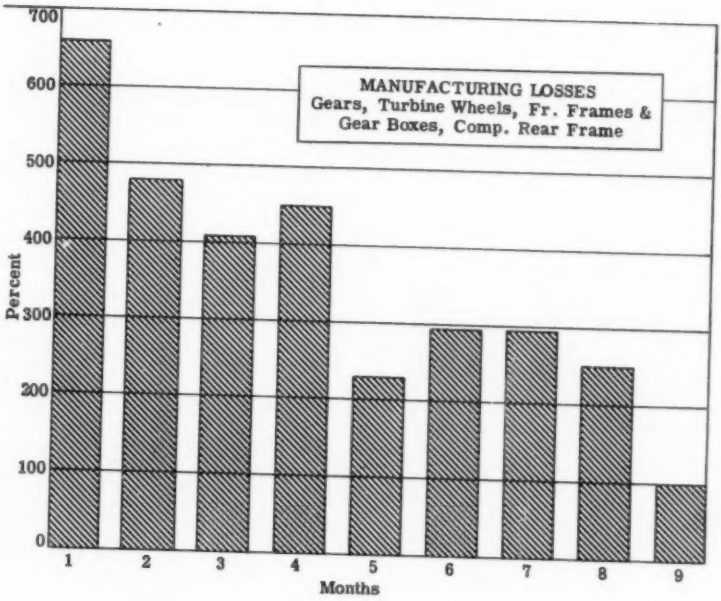


Chart 8

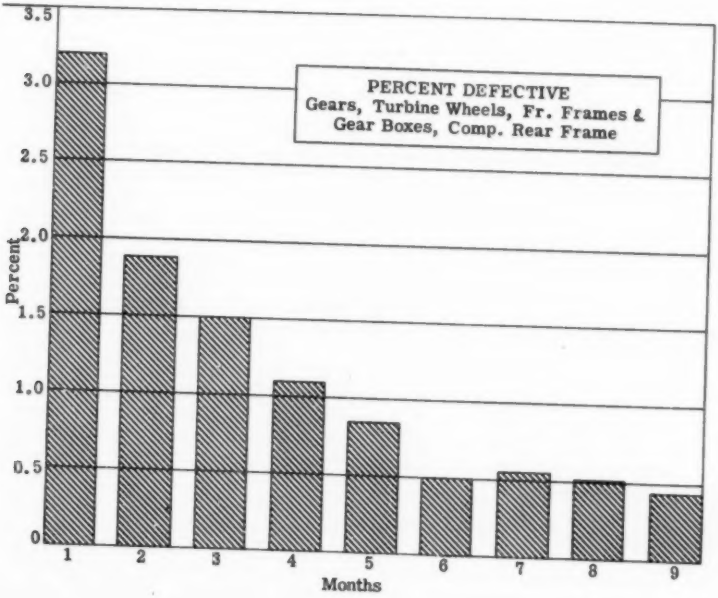


Chart 9

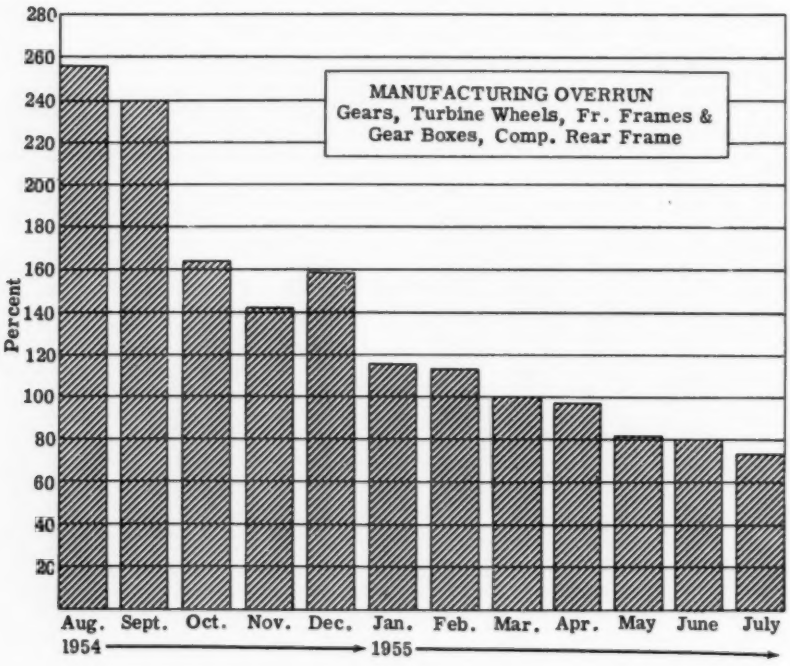


Chart 10

3. A continuous decrease in manufacturing overrun. (See Chart 10) The percentage shown is a ratio of overrun labor dollars over standard labor dollars. This ratio is a measure of the efficiency of Manufacturing against the planned time of a good completed component. The Master Quality Control System contributed to this reduction as a result of Manufacturing spending less time working on the parts (due to less scrap and rework) and Inspection checking fewer parts and having less paper work (because of the decrease in the number of discrepancies requiring special records and corrective actions).

4. Considerably reduced action by the Material Review Board (MRB) at the customer's plant. (See Chart 11) This index covers the major assemblies of a jet engine such as the compressor rear frame and compressor rotor. It represents the overall percentage of major assemblies that the customer found not meeting his requirements.

5. Considerably reduced MRB action at source.

6. Shorter product cycle time and less "in-process" inventory. Since fewer pieces are scrapped and reworked, less time is expended per part and fewer parts are scheduled to meet shipping commitments.

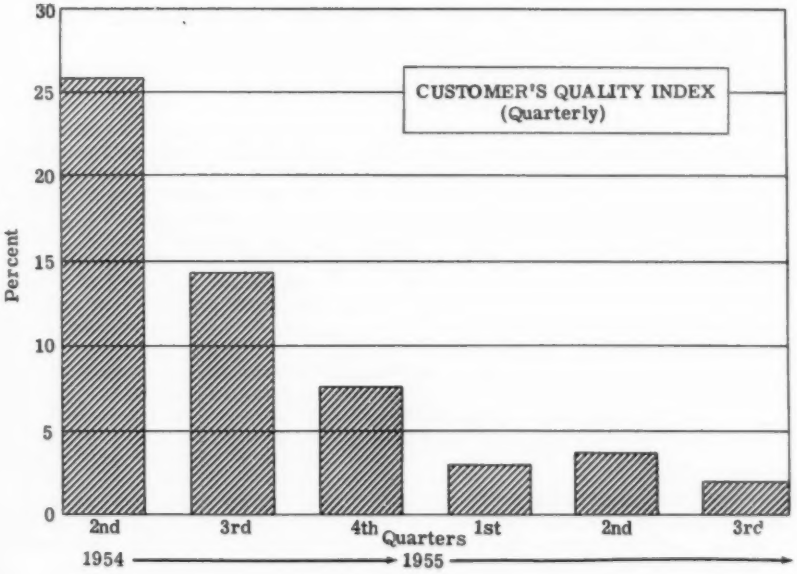


Chart 11

7. Improved Schedulability. Production control does not have the many panics resulting from scrap and rework, and therefore does not have to disrupt the normal flow of material by emergency orders.

8. More meaningful and complete quality records without duplication. It is obvious that if the achievements evidenced by this paper are to be duplicated or exceeded by others, Manufacturing must be alert to its problems and dogmatic in its effort to resolve them. Here, a "workable system" has been transformed into a "dynamic tool" through many innovations and effective teamwork.

HIGH QUALITY AT LOWER COST THROUGH WORK SIMPLIFICATION

Leonard C. Craig, Jr.
Texas Instruments Incorporated

During the past few years, as great strides have been taken in the development of new statistical techniques and the industrial application thereof, there has been an important category of quality control and inspection people who, even though impressed and encouraged by the statistical techniques, have reacted somewhat as follows, "Well, these techniques are wonderful for the manufacturer who produces thousands of the same product, but what can we in job shop situations do with short runs?" If you will think back to the technical sessions which you have attended in the past, you no doubt can remember this question arising many times.

This paper is not intended to provide a panacea for the short run problem, but rather to acquaint you with the Quality Control philosophy of Texas Instruments and to explain briefly one of the tools being applied at Texas Instruments which is enhancing this philosophy and contributing directly to the building of high quality products.

In order that you might have a more complete appreciation of the subject at hand, I should like to tell you just a little about Texas Instruments, the nature of our products and organization. Texas Instruments at present includes four separate and completely autonomous product divisions. These are the Apparatus Division, Components Division, Semiconductor Products Division, and Houston Technical Laboratories. Each division manufactures an integrated line of products in accordance with its technical skill and facilities.

In addition to the four product divisions, there are the subsidiary corporations of Geophysical Service Incorporated and Engineering Supply Company. GSI was one of the pioneers in the field of seismic exploration. During the past 25 years, GSI has operated seismic survey crews, working under contracts with major petroleum producers, in nearly all of the world's prospective oil provinces. Engineering Supply Company distributes industrial, electronic, geophysical, transmission, and safety supplies throughout the Southwest, representing some 500 manufacturers.

The Apparatus Division manufactures complex electromechanical instruments and airborne electronic equipment. The Components Division manufactures various electrical components such as transformers, coils, pulse-forming networks, precision carbon-deposited resistors, panel meters, and a line of subminiature transformers. The Semiconductor Products Division produces both silicon and germanium diodes, transistors, and rectifiers. Houston Technical Laboratories is currently engaged in the development and manufacture of petroleum instrumentation for use principally by the seismic exploration industry. My comments concerning short runs apply to the Apparatus Division and Houston Technical Laboratories since the very nature of the products of both the Components and Semiconductor Products Divisions allow their techniques to more nearly approach mass production conditions.

Time and again we have heard the familiar maxim that quality cannot be inspected into a product but must be designed and built into it. We

take this statement literally at TI, and therefore our entire Quality Control Program is built around the basic philosophy of placing the initial responsibility for quality on the department, shop and individuals concerned with the design and manufacture of the respective TI products. A manufacturing operation, whether it is fabrication, assembly, test or packing, is not considered to be complete until the operator reasonably assures himself that the operation conforms to the applicable drawing or specification.

Quality Control Inspectors are located in each of the manufacturing areas to take care of first piece and in-line inspection where special skills and equipment are required. But the responsibility for seeing that first parts are checked remains with the manufacturing personnel.

Assuming that the operators are adequately equipped, the effectiveness of the above philosophy is directly proportional to the "quality attitude" of the operators. It is not enough to simply place this responsibility for quality on the shops and individuals and hope that everything will turn out satisfactorily -- each individual must be willing to accept his share of responsibility for quality.

At Texas Instruments a great deal of energy is expended by management, supervision and the quality control group in developing a high degree of quality consciousness throughout the organization. This is accomplished primarily through thorough indoctrination of all personnel in TI's quality philosophy and procedures with special emphasis being placed on the importance of inspection by the operator as a part of every operation.

Since our quality philosophy is management-inspired rather than management-tolerated, quality consciousness is an important consideration when establishing programs in departments other than Quality Control -- particularly in the Methods Improvement Branch of the Apparatus Division. An excellent example of this is the Work Simplification Program, which has been in effect since January 1953. Even though this Program is designed primarily for the improvement of methods and cost reduction, it very definitely contributes to the program of developing quality consciousness throughout the organization.

Of course quality consciousness cannot be measured directly with an indicating type gage, but the results can be measured rather precisely by the inspection department in terms of fraction or percent defective. At Texas Instruments we utilize both acceptance sampling and 100% inspection depending upon the nature of the characteristic being inspected. Since we manufacture such a tremendous quantity of different parts, it is not economically feasible to classify each and every characteristic on every part into critical, major and minor categories in the usual fashion. We do, however, classify into these categories according to the magnitude of the tolerance applied to the characteristic in question. All critical characteristics are inspected 100% unless there is good factual reason for not doing so. An example of a good reason is the situation where it would be desirable to establish and maintain a process control chart of the X-bar-R variety and if the chart indicated good control within specification limits, the material would be accepted at the machine. It should be pointed out that in the short run situation this is a rather infrequent occurrence and as such does not interfere with the basic quality philosophy. All major and minor characteristics are inspected on

a sampling basis in accordance with plans from MIL-STD-105A. We recognize the limitations of the sampling plans in their ability to distinguish between very good and very bad individual lots particularly where the lot quantity is small, but the shop quality level in percent defective established over many lots is a very good measure of the quality performance of each shop.

In spite of our effectual philosophy and all the effort put into developing quality consciousness, we are not at all aghast to discover an occasional defective in the material submitted for inspection and, of course, when defectives are occurring, our thoughts immediately turn to the associated rework and scrap costs.

At this point, let's depart from the somewhat philosophical aspect of Quality Control in the short run situation and dwell for a few moments on the relationship of manufacturing cost to quality and the approach generally taken by Quality Control groups to the cost reduction problem.

Why are we as Quality Control people so vitally concerned with the lowering of manufacturing costs? The answer to this question, I believe, is two-fold. First, during the past 15-20 years we have been provided with some Quality Control tools in the form of statistical methods such as acceptance sampling, X-Bar-R charts, p charts and c charts, which through their application enable us in many instances to reduce inspection costs, improve process control such that less defective material is produced, and isolate defect-producing areas in order that corrective action can be taken thereby reducing rework and scrap costs.

Second, during these same years we have been made to realize more than ever that a quality product cannot be defined as simply a product which performs its intended purpose in a reliable manner. As important as this requisite is, there are at least two others. In order for a product to be called a "quality" product it must not only perform its intended purpose in a reliable manner, but it must also be available when the customer needs it and at a price which is reasonable -- this price, of course, reflecting the manufacturing costs.

A product may be the ultimate in quality of design and quality of conformance to that design, but if, as a result, the selling price is so high that the customer will not or cannot buy, then the ultimate is for nothing because a manufacturing organization cannot be maintained with a product which will not sell and provide a reasonable profit.

At the other extreme, if a product is so cheaply built that it will not even perform its intended purpose in a reliable manner, it then makes little difference how low the selling price is -- the customer will not buy at any price. Therefore our concern for manufacturing cost is because we recognize a reasonable manufacturing cost as one of the prime requisites of a quality product, and because we have available some proven statistical tools which enable us, in many instances, to reduce manufacturing and inspection cost.

The Quality Control approach to cost reduction is primarily through the prevention of defects. Defect prevention should be the prime objective of every Quality Control organization as opposed to simply sorting the good parts from the bad parts lot after lot. The prevention of defects is accomplished through the use of process control techniques

where practicable, the development of a high degree of quality consciousness on the part of the operators, or simply the accumulation of a history of inspection results showing the extent and nature of the defects occurring and through analysis of this history attempt to locate the area or areas producing the most expensive defects.

In the short run situation, some form of the history method is used to a greater extent than any other statistical method, because the nature of the work is such that, in general, the main objective is to prevent defects from occurring in rather broad areas rather than in detail operations. Now let's assume that our Quality Control Engineer has performed an analysis of the history of inspection results and has determined that a certain manufacturing area is producing a relatively high percentage of costly defects. We all know that the logical thing to do is TO TAKE CORRECTIVE ACTION. This sounds very easy, but many times this is the point at which the Quality Control Program becomes weak. The Quality Control Engineer when attempting to see that corrective action is taken is faced with the same problem as the Industrial Engineer when he begins to install a new method -- lack of complete cooperation on the part of the shops and the individuals actually performing the work. Why is this so? Actually this lack of complete cooperation can be attributed almost 100% to two natural human characteristics and they are RESENTMENT OF CRITICISM and RESISTANCE TO CHANGE. If you do not believe that this is a very real problem then consider the following editorial that appeared in a Boston paper about 80 years ago:

> "A man about 46 years of age, giving the name of Joshua Coppersmith has been arrested in New York for attempting to extort funds from ignorant and superstitious people by exhibiting a device which he says will convey the human voice any distance over metallic wires so that it will be heard by the listener at the other end. He calls the instrument a "telephone," which is obviously intended to imitate the word "telegraph" and win the confidence of those who know the success of the latter instrument without understanding the principles on which it is based. Well-informed people know that it is impossible to transmit the human voice over the wires."

Ridiculous, isn't it? But the statement was accepted by even well-informed people 80 years ago.

I mentioned earlier that the Work Simplification Program was making a definite contribution to the building of higher quality products. I would like to explain very briefly how this program is being applied at Texas Instruments.

A few years ago when our management felt the need for an over-all cost reduction effort, two alternates were considered. First, to take the expert approach requiring a relatively large number of industrial engineers to blanket all operations in the plant, or second, to take the general approach; that is, to tap the vast resources in the minds of all the people in the organization. After due consideration, management decided unanimously to take the latter approach. It was, of course, recognized that in order for this type of effort to be successful there must be a well-planned and directed program.

A Work Simplification Program appeared to be a "natural" since the basic philosophy of Work Simplification is so closely related to our

managerial thinking. The philosophy of Work Simplification might be summarized as follows:

(1) It's fun to participate. Practically all of us like to take part in group activity. We like to feel that we "belong" and to feel that our jobs are important.

(2) It is natural for people to want to improve and they will try to do so unless inhibited. One of the objectives of Work Simplification is to remove as far as possible any inhibitions or fears which might prevent the participants from improving.

(3) It is not what you say but the way that you say it. There are three ways of getting results through people -- you can tell them, you can sell them, or you can consult them. It has been demonstrated that the two latter methods are by far more effective than the first.

(4) It is not what you do but the way that you do it. Most of the jobs we do are necessary or we would not be doing them in the first place. There is, however, associated with the performance of each job a certain amount of wasted material, time or energy, or combinations of all three in the way the job is done.

The first step in establishing the program was to send a well-qualified person with both engineering and production experience to Lake Placid, New York, for six weeks of intensive training in the principles of Work Simplification. Upon return, this person was placed in charge of the Methods Improvement Branch of the Apparatus Division with the intention of training every individual at Texas Instruments in the principles of Work Simplification.

The Work Simplification classes are held in a specially designed and well-equipped conference room. The class itself consists of 16 people and is conducted during periods of two hours each, once a week, for 12 weeks or 24 hours total -- all on company time. The following are some of the more important principles taught during this 24 hours:

(1) The use of the Flow Process Chart, which is a chart for recording the performance of a particular job, operation by operation. This chart enables the investigator to make his analysis from facts instead of opinions.

(2) How to select the job to improve and how to break it down in detail, and to approach a better way through questioning each detail with What, Where, When, Who, How.

(3) The principles of motion economy, the use of equal and opposite motions of the hands, the optimum work area, the maximum work area which if exceeded makes it very difficult to obtain any reasonable facsimile of efficiency.

(4) Perhaps the most important aspect of the training is the continued emphasis given to overcoming resentment of constructive criticism and resistance to change. More emphasis is placed in this one direction than any other because people must be receptive to change and cooperate with one another if improvements

are to be made.

It would be preposterous to think that Work Simplification experts could be developed within the narrow span of 24 hours -- that is not the intent. The objective is to provide all the people with the BASIC TOOLS and to provide enough practice with these tools so that each individual can effectively apply them to his own particular job. Not to be overlooked is the fact that through this kind of training individuals are made to feel that they really belong to the TI team, which in itself is food for a healthy attitude.

If I have managed to express my thoughts clearly, it should be obvious to most as to the part that Work Simplification is playing to improve quality, but just in case the point is not clear, let's look at it in this respect. First of all, in a job shop or short run operation where the application of process control techniques of the X-Bar-R variety is somewhat limited, the next best is the assurance that your operators possess a high degree of quality consciousness, a personal desire to do a job right the first time, and a lot of personal pride in a job well done.

Second, because of the improved state of mind on the part of the shop foremen and operators as a result of the Work Simplification training, the Quality Control Engineer's job of seeing that corrective action is taken and the required follow-up is much easier than it would be without it.

Last but not least, since a reasonable manufacturing cost is actually one of the requisites for a quality product, every improved method and hence cost reduction contributes its share to the building of a higher quality product.

Similar aspects of the relationship of the Quality Control Department to Industrial Engineering was summed up very nicely by Mr. Warren Alberts of United Air Lines in a paper presented at this convention last year, when he said, "Quality Control has been dancing with inspection; and Industrial Engineering with production; for so long that they both have almost missed some very attractive partners."

CONTROLLING THE QUALITY OF BONDED PANELS-HONEYCOMB AND LAMINATE TYPE

John M. Joseph
The Glenn L. Martin Company

Countless products of industry are produced today and their end quality is maintained by the time proven formula; "Take an Engineering plan, add to it Manufacturing skill, and give direction to this skill through Process Control". And so it is with the bonding of panels, both Honeycomb and Laminate types.

To start with, we must have an Engineering plan that is producable, one that will give the skills of the shop the greatest possible latitude and yet maintain the quality requirements of structural integrity, dimensional and smoothness requirements.

Since today's bonded panels are a combination of sheet metal and machined parts, it was determined that the sheet metal details could no longer be fabricated to the dimensional tolerances that served so well in conventional types of assembled structures. Since the tooling used in Bonding must be very accurate in its dimensions, so it follows that the details must be very accurate and so another step in controlling the end quality of Bonded panels was established.

Since many steps are required to achieve and maintain the end quality of Bonded Panels, each one has to be treated for what it is worth and where it fits into the total result.

After fabrication of the details, the problem of cleaning and preserving this cleanliness is of paramount importance. Metal details are processed through a chromic-sulphuric acid bath and thoroughly rinsed. The effectiveness of this acid etch is determined by a Quality Control check for "water breaks" during the rinse. A break in the flow of rinse water over the surface of the details being inspected would reveal the presence of some form of contamination and necessitate the re-processing of the detail. Cleaned details, if not immediately coated with adhesive, are wrapped in clean paper to protect them. Storage is limited to 12 hours, after which they must be recleaned. At regular intervals, samples of the sheet metal details are run through the cleaning process with regular production parts. These samples are then bonded and shear tested in the Quality Control Laboratory as an additional check on the effectiveness of the cleaning and adhesive materials being used.

The liquid adhesive is sprayed on the cleaned metal surfaces, rolled on the honeycomb edges, and applied between the skin and core as a dry film. Great care is taken in the control of the viscosity of the liquid adhesive and its application to insure uniform thickness. The thickness of the adhesive sprayed on the skins is checked by micrometer for uniformity. The dry film is made to a standard weight which assures it uniformity in application.

The principal requirements in a properly bonded structure are clean metal skins and cores and adhesives applied uniformly. In addition, the details must be accurately positioned and the temperature and pressure at the glue line properly controlled. Accurate alignment is achieved with specially designed tooling which is periodically checked. When the details are fitted into the tool, they are inspected for adhesive coverage, cleanliness, time elapsed since adhesive application, and for fit.

Bonding temperatures and pressures are recorded by automatic controllers and these instruments are periodically calibrated.

In electric-blanket bonding tools, temperatures are automatically recorded on charts from thermocouples located at various points on the surface of the structure being bonded. This insures the consistent application of heat over the entire structure regardless of variations in its density. For example, the wing structure of the Matador contains a casting as well as areas of low density honeycomb. Careful control of temperature over the surface of this structure prevents distortion that might otherwise occur from differential heating. These charts become part of the assembly inspection record. Temperatures and pressures are watched by Quality Control personnel during the bonding cycle or recorded by instruments, as the case warrants. No phase of the bonding cycle is neglected. The "breathing cycle" in which the bonding pressure is released momentarily to allow the escape of trapped gases, is also closely regulated as this is an important step in achieving a high strength bond.

After the bond is made and the structure removed from the bonding tool, an Inspector makes additional checks. He visually examines the bonded surface for wrinkles, dents or blisters which would indicate faulty adhesion. He tests exposed joints for gaps with a feeler gage. He taps the surface with a small hammer, at the same time listening for an off-key note that would indicate a lack of bond.

The skill of trained Quality Control personnel is supplemented by the use of precision instruments. The structure is measured for dimensional accuracy in a number of ways depending on the particular job. In the case of high-production structures such as the Matador wings and stablizers, contour check gages are used.

A vacuum test is made on the bonded surface to further test the quality of the bond. This imposes a load on the face of the sandwich, if the skin is deflected more than a specified distance, measured in thousandths of an inch, lack of adhesion is indicated.

Finally, before the structure is accepted, sample buttons are cut from selected locations. These buttons are approximately three-eigths of an inch in diameter and represent a complete metal-to-metal bond including both metal surfaces and the adhesive. Examination and probing with a special tool under a microscope reveals whether the adhesion is good, fair or poor and whether the contact of the adhesive with the metal is satisfactory, partial or non-existent. The hardness of the adhesive, which is an indication of the degree of the curing, is also measured. The density of the adhesive is held to rigid Process Control specifications and is classed as solid, slight bubbles, bubbles or frothy. Only after all of these non-destructive tests have been made and accepted is the bonded assembly released for production use. Areas where buttons are removed are filled with Presstite putty to eliminate any possible leakage areas and to maintain smoothness requirements. Certification of button readers is maintained by a specially assigned Quality Control Laboratory technician who keeps abreast of the latest developments in bondline interpretations and imparts this knowledge to the certified personnel assigned to button reading. All questions concerning button reading are referred to this "control" technician.

In addition to the routine production controls and tests, the first production-bonded assembly is destroyed to determine the completeness of the bond. Portions of this first assembly are cut into randomly distributed specimens and tested to prove the structural integrity of the entire assembly. The passing of this test is certification that all tools and procedures are set up to produce uniformly high quality bonded assemblies.

Plans for the future for more exacting Quality Control of Bonded Panels include the study of the degree of cleanliness, air-conditioned buildings to eliminate contamination of finished parts, the use of Stub and Sonometer as a more positive control on the end product. It is also planned to establish Process Control personnel in the Quality Control Division whose function will be to monitor the Processes involved in bonding. Additional automatic devices are planned for the control of temperature, pressure and time, thereby eliminating the variations inherent in human effort.

The Martin Company will leave no stone unturned in seeking out and perfecting the techniques and controls necessary to produce bonded panels of the highest quality, second to none.

CONTROLLING INVENTORY AND PRODUCTION IN THE FACE OF UNCERTAIN SALES

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A decision rule, having great computational simplicity, is described for determining the amount of aggregate production in a factory for a given month that will minimize costs, under assumption of a cost function that is a positive, semidefinite quadratic form, and under conditions where future orders cannot be estimated with certainty. The relation of the procedure to other dynamic programming methods is discussed, and a number of problems requiring further research are indicated.

Introduction

The techniques to be reported in this paper were developed in the context of a specific industrial problem: to schedule the production in a factory of several thousand items for delivery to warehouses. The items are held in stock and delivered to the warehouses on demand, warehouse demand being based on rather widely fluctuating sales to customers. The product is manufactured by a batch process, with a fairly wide range of possible batch sizes. Moderate economies are obtainable from running large batches, and from proper scheduling of the product sequences; but within limits, manufacturing cost depends more on aggregate production than upon the exact product mix.

For sake of concreteness, we shall focus our attention on this particular manufacturing problem -- and even more specifically upon the problem of determining the aggregate monthly production quota. It will become apparent, however, in the course of the discussion that the techniques outlined here are applicable to a wide range of practical dynamic programming problems.

Aggregate Production: The Cost Function

As a first approximation, we assume that the costs we wish to minimize by programming can be divided into two independent parts: (1) costs associated with aggregate monthly production, and (2) costs associated with the product mix. Although there are undoubtedly some interactions between these two components of cost, it is believed that in many practical situations the interactions are small and can be ignored. In particular, this appears to be true in the specific industrial situation with which we have been concerned. (See (4)).

* Research undertaken for the project Planning and Control of Industrial Operations under contract with the Office of Naval Research.

In the long run, total factory production must equal total warehouse orders; in the short run, the difference between these two quantities will be taken up by fluctuations in stocks held at the factory. If long-run demand were known with certainty in advance, then a pattern of factory production could be determined that would be optimal (in the sense of minimizing total cost for the known demand). However, in the actual programming problem estimates of future demand are subject to substantial forecast errors.

The total production in the long run, then, is determined by exogenous factors -- warehouse orders. The cost incurred in manufacturing this total product will depend on the pattern of month-to-month factory production. The most significant variable costs appear to be the following:

(a) Inventory and run-out costs. To the extent that factory production precedes the receipt of orders, costs will be incurred from holding inventories; to the extent that orders are underestimated, penalties will be incurred (in the form of lost sales or loss of customer goodwill) from runouts of particular items.

(b) Costs associated with the level of production. Production costs will presumably be at a minimum if the factory is operated at a constant rate. If there are fluctuations in factory production, these will result in higher costs because of: premium overtime pay, under-utilization of labor during slack periods, and under-utilization of plant during slack periods. (The latter two costs will appear in the form of a larger labor force and a larger plant capacity than would be required if production were at a level rate.)

(c) Costs associated directly with fluctuations in production. Fluctuations in work force will result in employment and training costs, termination pay, and probably in lowered employee morale and productivity.

The total variable cost function, made up of these components, is undoubtedly a fairly complicated expression. To attempt to deal with it in a general form would lead to a mathematically intractible programming problem. The methods proposed here are based on an essential simplification of the cost function, but a simplification that, we believe, provides a sufficiently realistic and accurate approximation in this situation and many others to justify its use.

Under the limitations of present knowledge, we are faced with a choice between attempting to deal with the real situation in all its complexity in the face of almost insuperable mathematical and computational problems; or simplifying the problem to make its solution and the practical application of that solution exceedingly easy. We believe that the particular form of the cost function proposed here buys a great deal in the way of simplicity and compatibility at a relatively small cost in accuracy.

Our basic assumptions are four:

(1) that we wish to minimize the expected value of total costs;

(2) that the three basic components of the cost function -- inventory costs, production level costs, and production change costs enter the total cost function additively;

(3) that the total cost function can be represented as a sum of terms corresponding to the costs incurred in particular months, from the present to a planning horizon N months hence;

(4) that each of the three components of cost in each month can be approximated by a quadratic function -- this function remaining constant through time.

The cost function may then be written as a positive semidefinite quadratic form:

$$(1)\quad C = C_I \sum_{t=1}^{N} [I(t) - I_C]^2 + C_P \sum_{t=1}^{N} [P(t) - P_C]^2 + C_{PA} \sum_{t=1}^{N} [P(t) - P(t-1)]^2$$

where C_I, C_P, and C_{PA} are positive coefficients for the three kinds of costs; $I(t)$ is the inventory at the end of the t^{th} month, $P(t)$ the production during the t^{th} month; I_C and P_C are parameters of the respective quadratic functions. We shall not discuss here the way in which the parameters (C_I, C_P, C_{PA}, I_C, P_C) of the cost function were actually estimated. (See (4).) Our experience indicates that estimation is feasible, and, moreover, that fairly substantial errors of estimation will result in only moderate departures from optimal behavior. We also omit here other formulations of the cost function that we have used, involving additional variables but preserving the quadratic form.

One comment is in order regarding the third of the four assumptions listed above. This assumption does not imply that there are no interactions between the production level in one month and the cost incurred in another. The sequence of costs is linked by the inventories that remain at the end of each month, $I(t)$, and by the production level that is in effect at the beginning of the next month, $P(t-1)$.

Comparison With Other Approaches to Dynamic Programming

With the assumption of the cost criterion, (1), the problem (as far as aggregate production is concerned) becomes one of minimizing the quadratic form in the face of uncertain future sales. Since other investigators have dealt with similar dynamic programming problems, a few comments may be offered on the relation of their work to the methods proposed here.

(1) Linear programming. If a linear instead of a quadratic criterion cost function were employed, the problem could be handled by linear programming methods. Relatively little work has been done to date, however, on linear programming under uncertainty (But see (8)).

(2) Dynamic programming. Quite general dynamic programming models have been formulated by Bellman (1), on the one hand, and by Dvoretzky, Kiefer, and Wolfowitz (2) on the other. These investigators have provided important theorems demonstrating the existence and uniqueness of solutions under very general conditions. By the specific examples they have examined, they have also demonstrated the magnitude and complexity of the mathematical and computational problems involved in obtaining actual numerical solutions. The methods employed in this paper constitute a special case of the general dynamic programming model, but a special case that -- thanks to the form of the criterion function -- leads to exceedingly simple mathematics and computation.

(3) Wiener's prediction and smoothing methods for stationary time series (7). We have not established in detail the relation between Wiener's methods and our own, although we have experimented with his techniques (3). A few facts are clear: (a) we are not limited to autocorrelation forecasts; (b) both approaches require the assumption of a quadratic criterion function. It would appear that in the special case where autocorrelations are used as the basis for prediction, the two methods should be identical, but we have not proved this.

If dynamic programming is to become a tool of practical value, then it is of critical importance to put problems in a form that permits the required parameters to be estimated and the required computations to be performed. It might be argued that with the availability of increasingly powerful computing devices, computational simplicity is of secondary importance. But anyone familiar with the capacities of present and prospective computers is aware that even very "simple" problems of the real world tax the resources of computers, and that simplifications almost always have to be introduced. The strategy adopted here is to incorporate these simplifications in the criterion function, and to do so in such a way that the resulting problem can be solved exactly.

Obtaining the Solution

We have the definitional identity:

$$I(t) = I(t-1) + P(t) - S(t) \tag{2}$$

where $S(t)$ is the quantity ordered by the warehouses during the t^{th} period. By substituting (2) in (1), we can obtain the total cost as a function of the P's and the S's alone. The S's are exogenous variables; the P's are controllable variables whose optimal values are to be determined. Hence, we are confronted with a variational problem of the usual kind -- in this discrete case, actually a simple minimization problem -- which can be solved by differentiating partially with respect to the P's to form the Euler-Lagrange equations. The following consequences are obvious:

(1) If the cost function can be expressed as a sum of quadratic terms -- as in (1) -- then the Euler-Lagrange equations will be linear. The converse is also true. 1/

(2) In the discrete case with which we are dealing here, the solution takes the form of a linear matrix equation:

$$\bar{P} = A\bar{S} \tag{3}$$

where $\bar{P}$ is the vector whose components are the P's, $\bar{S}$ the vector of the S's (with the initial conditions incorporated in the first few components), and A is a matrix whose components are functions of the constant coefficients in the cost function.

Since the vectors and matrix of (3) have N and N^2 components, respectively, and since N is large -- the distant future has some relevance, however slight, to the present production decision -- it would appear that the solution of the equations might present serious difficulties. Fortunately, this is not the case. We can, in fact, given certain conditions of boundedness on $\bar{S}$, assume N infinite. The elements of the inverse of A, with N infinite, can be obtained in closed form, beginning with the element in the upper left-hand corner, and proceeding across each row or down each column. Since P(1) depends only on the first row of this matrix, we can obtain an approximation up to any desired number of terms without inverting the entire matrix. 2/

Up to this point we have not added the complication that the S's are not known with certainty, but are only forecasts. But again, the quadratic form of the criterion function comes to our aid. If we generalize the problem by replacing the S's by a joint probability distribution, we find that only the unconditional expected values of the S's appear in the solution, (3). Hence, in the case of an uncertain forecast, we simply use the expected future orders in place of known future orders, and carry through the computations as before. 3/

We are now in a position to appraise the substantial advantages to be derived from the use of a quadratic criterion. (a) The entire problem is reduced to the solution of a matrix equation. (b) The matrix we obtain has special properties that make its inversion computationally easy. (c) There is no need to estimate the variance or higher moments of the probability distribution of sales forecasts errors. This is not to say that any and all problems should be cast in quadratic form. But the resulting gains are sufficiently substantial to justify a serious attempt at a quadratic approximation to the criterion function where this appears to be at all reasonable.

1/ See Herbert A. Simon, (5).

2/ These results are presented in two papers in Management Science (4).

3/ For a proof, see Herbert A. Simon (6).

The Item Scheduling Problem

We have now indicated how the optimal aggregate production can be determined for the factory each month. The problem remains of allocating this aggregate production to individual items, and scheduling the items. There are at least three approaches to the determination of the item allocations:

(1) We can formulate this as a static linear programming problem of reasonable size. We simply include P, the total production, as one of the constraints that the solution must satisfy. Then, we have factored the original dynamic problem, involving, say, 3,000xN variables, into a quadratic programming problem involving N variables (only one of which has to be determined each month), and a 3,000-variable linear programming problem to determine the item production schedule.

(2) Well-known maximization methods can be used to determine the optimum batch sizes and buffer stocks for each of the individual items. By modifying these to methods for finding constrained maxima--the total production specified by the aggregate rule constituting the constraint--they can be used to determine an item production schedule that will be consistent with the aggregate rule. An experiment is now going forward to apply this technique in a factory that had previously been using an electronic computer to determine optimum batch sizes and buffer stocks without constraints on the aggregates.

(3) A simpler technique will be described here which, while it can make no claims for "optimization," appears to operate satisfactorily in the particular factory situation where our first investigations have been carried out. Its application to other situations would have to be examined in detail.

The basic assumption underlying the simplified method is the following: for any given total inventory, it is desirable that the inventories of individual items be roughly proportional to the expected orders of those items.

Let I be the aggregate net inventory on hand now, and P the aggregate production planned for the next month (as determined by the quadratic criterion method). Let I_i be the inventory on hand (or shortage, if I_i is negative) of the i^{th} item and d_i the percentage of expected total orders represented by the i^{th} item. (The d_i sum to 1 over all items) A production schedule that will satisfy our aggregate rule consists in producing the quantity P_i of the i^{th} item, where:

$$P_i = d_i(I + P) - I_i \tag{4}$$

Undoubtedly, a more satisfactory rule can be devised by using a more sophisticated procedure for determining the desired quantities of the individual items. However, the rule of thumb outlined here appears to operate reasonably satisfactorily in our specific case. Whenever the inventory at the end of one month is seriously out of balance, the rule concentrates production on items with low inventories.

Additional Research Needed

We should not like to leave the impression that we regard the dynamic programming problem as "solved." We believe that we have constructed a simple procedure, with strong theoretical justification, that has applicability to a considerable range of practical situations. Our initial work with quadratic criterion functions has been sufficiently promising, and has shown itself sufficiently practical in application, that further explorations along these lines appear desirable:

(1) A deeper understanding is needed of the relation between the kind of dynamic programming model used here and Wiener's predicting and filtering techniques. In particular, our procedure has taken the forecast as "given," and has not dealt with the problem of devising optimal forecasts.

(2) The technique employed here of factoring the entire dynamic programming problem into a simple aggregate problem, on the one hand, and a static linear programming problem on the other would appear to have broader implications. The general principle of factorization needs to be extended in order to bring a wider range of practical problems within the limits of computational feasibility. Determining the appropriate points in the procedure at which to introduce essential simplifications is a crucial issue in applied mathematics. A more general investigation of "factorability" appears to be a promising approach to this issue.

(3) We are in need of techniques of sensitivity analysis to determine what accuracy is required in cost coefficients and forecasts, and what costs are incurred from inaccuracy.

(4) Nothing has been said in this paper about the warehouse ordering policy. We have treated the warehouse orders as though they were sales to ultimate consumers. In reality, of course, we have a cascaded system in which optimal production, inventory, and ordering policies need to be determined simultaneously.

Work on these problems is continuing at Carnegie Tech and other institutions, and it is probably not too optimistic to suggest that within two or three years a collection of techniques applicable to a broad range of problems of inventory and production control will be available in a form permitting ready application to industrial situations. Our experience with such techniques suggests that approximating the relevant cost functions by quadratics is a powerful and flexible method for keeping the computational requirements within bounds in dealing with extremely complex inter-connected systems.

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THE QUALITY CONTROL MANAGEMENT POLICIES OF THE DEPARTMENT OF DEFENSE

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This opportunity to address the Tenth Annual Convention of the American Society for Quality Control and to discuss the quality control program of the Department of Defense of the United States is most welcome and appreciated. It is not often that representatives of the governments and industries of both Canada and the United States have an opportunity to meet with each other and to talk over their common problems. This is an ideal forum for that purpose. I am sure that highly beneficial results will flow from the interchange of ideas which this forum makes possible.

Before discussing some of the details of Department of Defense (DOD) quality control policy, I think it is pertinent for me to indicate broadly my attitude toward the nature of policy making itself and my concept of the function and scope of quality control. In any area of government or industry, an administrator's concept of the nature of policy is pertinent to an evaluation of what he says and does. I need hardly tell you that it is very difficult to define the word "policy" exactly and comprehensively; it is one of the most elusive in our language. To me, policy making is primarily a calculated and precise decision-making process. By objectively weighing numerous influences and alternate courses of action, the policy maker selects one course of action as optimal for achieving a particular objective. Sound policy development is the antithesis of hunch and caprice. Policy is not something static. If it is static, it ceases to be alive and responsive to the changing environment.

Perceptiveness to change is basic to sound policy development because almost everything is constantly changing. Policy making consists of surveying the changing scene and adjusting one's course to arrive safely at an intended port of call. It is the policy maker's responsibility to take note of the interplay of action and reaction and to be ready to re-chart the course if new circumstances assert themselves. In quality control, it is particularly important to keep in mind that we are talking about a field of activity that is evolving and changing very rapidly. Policy in quality control must be responsive to the changes that we observe every day in mathematical statistics, industrial engineering, production, marketing, standardization, and in military logistics and supply generally.

THE SCOPE OF QUALITY CONTROL

Let's ask ourselves, at this point, what we mean when we use the words "quality control". Those words certainly encompass more than mere inspection and the use of sampling and other statistical techniques. Quality control relates to the total activity by which a product or a service is developed, produced, and utilized to serve the requirements of the consumer. The Department of Defense has attempted to indicate this thought by defining quality control as follows:

> "Quality control is that management function by which (1) conformance of material to quality requirements is assured;

(2) performance of material is measured; and (3) in the event that defects occur, corrective action is taken."

It is important to point out that this definition stresses not only the importance of controlling and properly evaluating quality during design and production, but control of the product -- quality-wise -- throughout its life history; it takes cognizance of the need for interaction between data related to the performance history of the item and to planning for inspection and quality control during any subsequent production of the same item. From this point of view then, the ultimate evaluation of quality involves (a) the determination in the factory and in the laboratory whether or not a product conforms to the requirements of the consumer, and (b) the determination of the performance effectiveness of the item. Conformance and performance are the twin measures of quality. It is the objective of quality control, broadly speaking, to assure that a product conforms to requirements and performs reliably and adequately in service.

DOD ORGANIZATION

Now, let me sketch very briefly the organizational structure of the DOD within which quality control policy is formulated. As you know, reporting to the President is a civilian Secretary of Defense who is responsible for the over-all operation of the defense activities of the United States. The Secretary of Defense has nine Assistant Secretaries, one of whom is the Assistant Secretary for Supply and Logistics. Under this Assistant Secretary is a Directorate of Cataloging, Standardization and Inspection. This Directorate is responsible for formulating all DOD policy in the field of quality control. Policy is transmitted to the Secretaries of the Army, Navy and Air Force who further transmit it to their various bureaus and technical commands. For purposes of my discussion, it is unnecessary to indicate the further chain of command within each of the services. It suffices to say that the service secretaries have great latitude in administering the affairs of their departments and are subject only to the broad policies emanating from the Office of the Secretary. The implementation of policy, including the development of supporting procedures and techniques, generally is the responsibility of the military services.

BACKGROUND OF POLICY

At this juncture you might well ask, "What are the basic influences on DOD quality control policy?" Or, put it another way, "What are the considerations that motivate policy?" I need hardly say that these influences are quite numerous and not easily subject to categorization. Broadly, however, I would say there are six basic situations that influence our thinking. At the risk of oversimplification, these influences may be classified under the following headings: (1) Design; (2) Production; (3) Economics; (4) Personnel; (5) Military Organization; and (6) Performance Effectiveness.

DESIGN

Design is becoming immensely complex. I realize, of course, that the word "complex" has been "done to death". Everyone in government and industry uses the word "complex" with different subjective interpretations of what "complex" really means. Without attempting a definition, I think that you will agree with me when I say that a guided missile or

an aircraft engine is complex. We know that items such as these have almost an infinite number of quality characteristics and that it is not possible for the consumer to evaluate the conformance of these characteristics to design requirements. Sometimes the requirements for instrumentation of items such as these are so expensive and so difficult that it is not possible for the government to perform adequate inspection and testing. I mention these things merely to point up one fact — that as industry and technology make further advances, the old concept of "caveat emptor" necessarily goes by the board. We can hardly escape the fact that unless the product is made right in the first place, unless it is properly controlled during manufacture and properly tested during and after production by the producer, the consumer can have little hope of getting the item he really needs.

Abandonment of the "caveat" philosophy is necessary on two counts. The prime suppliers of modern, complex military equipment need the type of assurance that stems from building the "components" right in the first place, and from the protection provided by their vendors' maintenance of adequate quality control systems. The government must place increased reliance on producers because it cannot economically provide the type and amount of inspection necessary to protect itself effectively against the receipt of sub-standard material. This is particularly true in times of emergency.

PRODUCTION

Since the days of Eli Whitney, the techniques of mass production have been evolving towards a greater speed and intricacy. As production accelerates and production procedures become more and more involved, quality is directly affected either favorably or unfavorably. Even though a production process may be well engineered, it is still possible that the process may generate defective material -- and at a high rate of speed. Within a mass production framework, quality control does not serve its purpose unless it is capable of signaling defectiveness as soon as a process goes out of control, or even before it goes out of control. The "automation" of production must be paced by a similar "automation" of quality control. Mechanized inspection must detect even the first defective unit. In modern industry, quality control is fast approaching the point where it must be preventative, or it is not worth its salt. If it performs in the manner of a policeman who catches the culprit after the crime, quality control is not technically or economically satisfactory.

ECONOMIC IMPLICATIONS OF QUALITY

This is a subject that has not been explored deeply and in concert by the economists, statisticians and engineers. With available improvements in statistical and engineering techniques that potentially offset the greater demands imposed by new design and production innovations, there is real need for all of us to face squarely the issue of the effect of quality control techniques, including acceptance inspection, on the total cost of production. I hardly need tell you that it is easy to go overboard on quality. It is natural for a designer to bolster his chances for a successful design by making demands for "high" quality when lesser levels of quality would be entirely satisfactory for a particular purpose. Products that approach perfection can be manufactured, but at the cost of insolvency.

In the DOD, we are concerned with establishing a proper balance between quality requirements and cost. Frankly, however, we do not have the tools for making the analyses that are necessary for this purpose. For example, in acceptance sampling, we do not have techniques for fixing acceptable quality levels so that they accurately represent on one hand the real needs of consumers and, on the other hand, the ability of the producer to conform economically to established levels of quality.

Within this area of economics also, I think it is well to keep in mind that quality control plays a major role in maintaining the effectiveness and integrity of the DOD competitive procurement system. Without a properly planned DOD quality control policy, competitors who maintain satisfactory quality would soon be driven out of business by sub-standard competitors who submit defective supplies on the chance that government will not detect deficiencies. In general, then, the economics of quality control -- as distinct from quality control methodology -- is of critical importance in charting quality control policy. Quality control, after all, is not an end in itself; it is a means to more economic productivity.

PERSONNEL

Any organization is only as good as the people who comprise it. This is as true of quality control as anything else. In the past, it has been a real problem to achieve recognition for quality control as a fully professional activity. This is still largely true and severely limits our ability to obtain the caliber of personnel that is necessary to do an effective job in quality control, particularly at the supervisory level. It has been a long tradition, as you well know, for inspection -- the progenitor of quality control -- to be a semi-skilled occupation. Industry has made real progress in discarding the hoary ideas that inspection involves only the use of go and no-go gages, and that the inspector is properly the low man on the totem pole. Quality control will not make real progress until it has at its command the services of highly trained managers, mathematicians, statisticians, and engineers. The DOD is fully cognizant of this fact. At the same time, we must acknowledge, however, that not everyone shares this conviction and that quality control faces a real challenge to prove itself a professionally motivated and a professionally competent element of industry and government.

So much for the caliber of personnel. There is another and equally important personnel consideration which must be dealt with when establishing quality control policy. I refer to the problem of establishing some correlation between the inspection and quality control workload and the manpower available for its accomplishment. Both in industry and in the government, we lack standard workload factors which can be used for an efficient coupling of work assignments and personnel allocations.

MILITARY ORGANIZATION

The DOD is a gigantic organization -- far too expansive in its scope and depth to come within the range of any one single person's comprehension. It involves a budget of 36 billion dollars a year. Its inventory alone represents a value of 100 billion dollars. This organization is world-wide in its operations. It involves not merely production, but also maintenance, storage and operations. The bigness and challenge of such an organization is something that we have to confront when formulating policy. Probably the best we can do is try to make our policy as

explicit and as simple as possible and leave it to the operating elements to use their ingenuity to implement it in the light of their own needs. That is exactly what the Department does. It proposes broad policy, but does not attempt to tell the military departments precisely how to do their jobs.

Parenthetically, I should like to mention here that quality control policy of the DOD pertains not only to procurement but also to maintenance and storage. Much of the materiel that is delivered to the armed forces is procured from industrial sources but large quantities are also fabricated at government facilities or withdrawn from maintenance, supply and storage activities. The source of materiel is not a matter of concern to the soldier, airman or sailor. It is of concern, however, that this materiel, whatever its source, does conform to the quality requirements of the DOD. In this paper I am primarily concerned with procurement policy in order to keep it within reasonable limits. However, I do want to accent the fact that the DOD takes the view that the maximum benefits of an inspection and quality control program cannot be realized unless the various facets of the program (procurement, maintenance, storage, supply and operations) and quality control's relationship with other logistic activities are properly coordinated at a high management level.

PERFORMANCE EFFECTIVENESS

I have already made mention of the fact that the twin measures of quality are "conformance" and "performance". It is not enough to inspect and test an item in the factory or in the laboratory to get a true measure of the product. "The proof of the pudding is in the eating." Accordingly, the ultimate measure of quality is the effectiveness and reliability of the product in service.

There was a time when a discussion of performance quality would have been completely frustrating and academic because, until quite recently, neither government nor industry had at its command equipment for swiftly and accurately measuring performance. During the post-war years, this situation has changed spectacularly. We now have at our disposal a wide variety of computing and tabulating equipment that permits us to obtain performance data in the field and to relate this data to design and procurement as well as to manufacturing and quality control operations in the factory. All of this is particularly pertinent to the formulation of quality control policy because, in the final analysis, the adjustments that are made in a quality control program must reflect the performance of the item in the field. The DOD is intensely interested in correlating its design and "in factory" quality control planning with performance data made available by the operating commands. We hope that, over a period of time, our quality control program will be focused on those aspects of manufacturing, inspection and testing which performance history has demonstrated are most benefited by effective controls.

POLICIES

Earlier I mentioned that change is the keynote of the environment in which we live. Change, by its very nature, creates problems. It is pertinent, then, to point out that while the DOD has published certain basic policies in quality control, there are problems -- challenging ones -- for which the DOD presently does not have policy answers. In presenting this paper, then, I will discuss first the policies presently

in effect and, secondly, I will discuss policy problem areas which are of concern to us.

BASIC QUALITY CONTROL POLICY

The really elemental policy of the DOD is that the military services in their relations with contractors must place reliance on objective evidence of quality and quantity. In so doing, optimum use will be made of contractor data. Let me read this policy as stated in DOD Instruction 4155.6:

> "Determination of conformance of the product to contract requirements shall be made on the basis of objective evidence of quality and quantity. The government inspector shall make optimum use of quality data generated by contractors in determining the acceptability of supplies. To the extent that contractor quality data are available and reliable, as determined by the government inspector, such data shall be used to adjust the amount of government inspection of products for acceptance purposes to a minimum consistent with proper assurance that the supplies accepted conform to the quality requirements established by the procurement documents."

This, then, is a departure from the old line of thinking that the consumer should check everything to protect himself, presumably, from the errors or malfeasance of the producer. This policy does not mean, however, that the government should buy "sight unseen". On the contrary, it is incumbent on government to verify the reliability and comprehensiveness of the contractor's inspection. The means by which such verification is achieved and, in fact, the methods by which an effective relationship is maintained with contractors, is beyond the scope of this particular paper. I am happy to say, however, that the military departments have made considerable progress in establishing methods of operation that are highly satisfactory and effective as judged by both government and industry.

STANDARDIZATION POLICY

The second area of policy has to do with standardization of supply. If we can keep the number of different things serving a single purpose to a minimum, we are in a much better position to control these things. It is equally apparent that if we can minimize the number and variety of quality control procedures and requirements, we further improve our management capability. The Standardization Program of the Department of Defense is the vehicle by which we reduce the number and variety of items in supply channels and standardize the quality assurance requirements contained in specifications. This program also promotes uniformity of inspection standards and procedures other than those contained in specifications.

The Department of Defense recently embarked on an accelerated standardization program which has considerable impact upon quality control policy. The standardization program has the following objectives:

1. Adoption of the minimum number of sizes, kinds or types of items.
2. Achievement of optimum interchangeability and compatibility.

3. Development of standard terminology, codes and drawing practices.

4. Provision of the most reliable equipment through the adoption of materiel evaluated in accordance with established specifications and standards.

5. Preparation of purchase documents to insure the delivery of items consistent with the Defense Standardization Program.

With respect to the last objective, the preparation of specifications to serve as purchase documents, substantial change in approach has occurred in the last few years. Earlier, specifications frequently reflected a designer's dream rather than a manufacturing capability. As a result, quality control devised tools to make the specification compatible with industrial capability. The new Defense Standardization Program, however, carefully makes a distinction between development progress and production capability. Care is taken to assure a broad and dependable procurement base by making specification requirements realistic in terms of realizable objectives. Moreover, specifications must be checked frequently for their compatibility with the progress of technological development and the current state of industrial practices.

Because of the revised approach to the specifications requirements, it becomes necessary to re-evaluate quality control procedures to insure that they are equally realistic. These procedures must provide tools which are capable of being selected objectively and are of demonstrable accuracy and effectiveness. They also must strike a proper balance between theoretical development and accepted recognition and use. A much-to-be-desired result of this coordination between specifications requirements and quality control programs will be a marked increase in the reliability of equipment.

MANAGEMENT POLICY

The third element in policy relates to management. Sometime ago, the National Industrial Conference Board published a report as a result of a survey of military inspection. Among its recommendations were (1) that duplication of inspection among the military services be eliminated; and (2) that duplication between government and industry be eliminated. The policy statements in DOD Instruction 4155.6, to which I have already referred, go a long way towards solving the industry-government duplication situation. To strengthen its efforts to eliminate duplication among the military services, the DOD published a directive, 4155.7, on 6 February 1956, which reads as follows:

> "Procurement inspection at suppliers' plants shall be conducted by a single military inspection activity, except as provided in Section V. below. Such inspection by a single inspection activity shall be achieved by interchange of inspection services within and among the departments of the Army, Navy and Air Force. The military departments shall take positive action to eliminate multiple inspection assignments."

As a result of this policy, we have eliminated duplication of inspection representations in 99 percent of all manufacturing facilities

under contract with the DOD. This interchange of inspection services has presented and is continuing to present many problems. By and large, however, the program has been eminently successful. In our quality control, inspection and standardization programs, we are gradually developing standard techniques to eliminate the problems that inevitably arise when military services, with different traditions and techniques, attempt to perform inspection for one another.

POLICY PROBLEMS

In my opening remarks I emphasized that perceptiveness to change is an essential qualification for anyone who presumes to make policy in business or in government. I also underscored the fact that change, by its very nature, creates problems. In the field of quality control, I don't think it is unfair to say that for many years, up until the time of Shewhart's work, inspection was quiescent. There was very little in the way of new concepts and new methodologies. But with the advent of Shewhart and with later developments in the field of sampling, particularly under the impetus of World War II, inspection and quality control felt the impact of many new and challenging ideas. These ideas derive primarily from mathematical statistics, but also from industrial engineering and management. As a result, problems have arisen that all of us are now attempting to solve. This is no less true of the DOD than other military or industrial organizations. Without making this paper overly lengthy, may I indicate roughly what some of these problems are?

For purposes of simplification, it might be appropriate to classify these problems under two headings: (1) the consumer-vendor relationship; and (2) quality control requirements. Incidentally, it is well to reemphasize that I am speaking from a DOD point of view. While I am sure that these problems have interest beyond government, my personal concern is colored by my responsibility as an executive of the DOD.

CONSUMER-VENDOR RELATIONSHIP

We all acknowledge, I assume, that quality control must serve a "preventative" purpose. We also assume that for many items, particularly military equipment with important reliability requirements, it is almost impossible for the consumer to evaluate adequately the acceptability of an item at the time of acceptance.

Among the objectives of the quality control program of the DOD is the "prevention and prompt detection of defects". The problem, then, that presents itself is this. Does a consumer have the right to demand of a producer that he produce a product under controlled conditions? Let's frame this question more precisely in terms of the government-industry relationship. Is it proper for the government to ask the producer to so manufacture his product so that he not only delivers an item that conforms to the blueprint but that this product be manufactured under appropriate control of quality to (a) assure reliability in service and (b) conserve equipment and resources? Assuming that the contractor is responsible for the control of quality, by what modus operandi can government and industry collaborate to realize objectives of reliability and conservation without risking interference of government in industry?

Among the other objectives of the Department's quality control program are the following: (1) to eliminate duplication between government and industry and (2) to achieve maximum government-industry cooperation.

At first sight, all of these objectives are undoubtedly valid. They might even be called "noble". No one questions that in times of mobilization, government and industry operate as a kind of joint enterprise. The fact still remains, however, that it is extremely difficult to elaborate a mode of operation by which these objectives can be achieved to the satisfaction of government and industry with each restricting itself to its proper orbit of activity.

QUALITY CONTROL REQUIREMENTS

With the development of statistical techniques, the field of acceptance inspection is taking on an aspect which was unknown twenty-five years ago. While great statistical progress has been achieved, the same does not appear to be the case in terms of management criteria and alternatives. There are questions with respect to the application of the techniques which must be answered clearly so that they will be understood by all -- the designer, the user and the producer.

There are basic questions that require answers. How, technically and contractually, should the consumer specify his product quality requirements? Should the consumer specify acceptable quality levels and delineate specific quality characteristics of the product that must be measured, tested or otherwise evaluated? If such criteria are established, should that constitute legal definition of quality binding on both the consumer and the vendor? If acceptable quality levels should be established by the consumer, by what criteria should these levels be chosen? What is the relationship between quality levels and price? What is the economic loss or gain to the consumer if he admits to accepting less than a hundred percent quality? In light of the new concept of realistic specifications, is the acceptable quality level still intended to equate specifications with industry capability? If so, with what type of producer -- low cost, high cost, marginal? Let's for the moment assume that for certain types of equipment it is reasonable for the consumer to demand of the vendor that he have satisfactory quality control system. What constitutes a satisfactory quality control system? What are the minimum key managerial and technical controls which must be maintained in any production process as a basis for presuming that the product will perform satisfactorily in service?

In posing these problems, I hope that I am not suggesting that we are completely at a loss to suggest their solution. As a matter of fact, each of the military departments of the DOD have made outstanding progress in finding solutions to these questions. However, the problem of management in the DOD is to formulate or adopt that solution that is optimal for the DOD as a whole. Some of these questions require considerable research. Such research is already in progress.

These problems are the inevitable concomitants of progress, manifestations of the dynamism of quality control. These are not issues to be evaded or prejudged. We have reason to be happy that the progress of quality control has made it possible for government and industry to come to grips in a realistic and scientific manner with problems that, in the past, were not amenable to objective analysis. By research and study, the DOD is confronting these problems and gradually evolving new and improved techniques for producing better military equipment to protect the peace of the world.

STATISTICS SHARPEN THE BREWERS QUALITY CONTROL TOOLS

Robert I. Tenney and Marjorie L. Sutherland
Wahl-Henius Institute

The methods for making beer have remained essentially unchanged for many centuries. There have been refinements in equipment and improvements in process guidance, but the raw materials and the basic process are the same today as in pre-medieval times. The reasons for this also dictate that the product be treated batchwise.

The changes which make malt of barley and those involved in converting starch into sugar by malt as well as the fermentation of sugar into alcohol by yeast action are all life processes of animate matter. The laws governing the direction and the extent of these life processes are the same today as when plants first grew on earth. Growth time determines the duration for each of several batch step operations. From a quality control concept the brewing industry has parallel problems to those of many other batch processes.

Since the invention of the thermometer and the hydrometer, brewers have been recording quantitative data about their process and product. Each new analysis or method of measure that can be related to beer has been adopted to aid in the control of quality. Today, every brewer habitually makes many measures of his performance. Evaluation of these statistics considering the laws of probability has proven of much value to brewers.

Assurance of Incoming Quality

Brewers buy processed grains as their major ingredients. These are sampled and analyzed usually in car load lots and the test results are compared to specifications. Statistical concepts are involved in the sampling methods and variation is recognized. For several years the American Society of Brewing Chemists has been presenting the data of collaborative inter laboratory analyses of malt in a series of frequency distribution diagrams with values of standard deviation.

The setting of realistic specifications follows the pattern of any other industry. The first submitted are frequently too narrow to be met. Discussion and mutual understanding of both buyers and vendors problems result in workable specifications. Performance of different vendors is frequently compared through a series of histograms. Fig.1 is a typical device of this nature. Seven different maltsters were supplying this brewer, all attempting to meet the same set of specifications. The histogram for one measurement for all cars received shows as the outline while those cars received from two individual suppliers are shown as shaded areas.

In this case the measure is for extract on the as is basis which was related to a minimum specification of 72.3%. No maximum value was set. One maltster grouped his shipments with precision at a mid value of 72.7% shown by the dotted area. Another had better performance but greater spread indicated by the solid area. Now the brewer experienced less brewhouse yield from the "better" malt with the highest extract. Reference to other measures indicated that both maltsters were meeting other specifications but that the one denoted by solid areas was including more

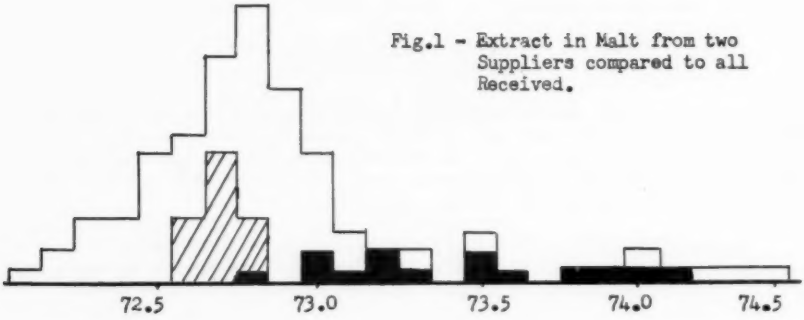

Fig.1 - Extract in Malt from two Suppliers compared to all Received.

large kernels than was the other. A revision of the specifications to exclude more than a minimum number of largest kernels gave the brewer better performance and saved the maltster money. It also brought all suppliers more in line.

Typical acceptance sampling and incoming inspection methods have been applied to commodities such as bottles, crowns, cartons and other items used in the packaging operations.

Process Control

The use of the standard $\bar{X}$, R and p charts is of considerable help in guiding the processes. Two characteristics of the brewing industry, however, offer advantages not always held by other process industries. If a metal part fails to meet a minimum specification it can only result in wasteful scrap. In brewing even the "out-of-control" batches can be and are blended with others so that waste is not a problem. In fact routine blending of all batches in a progressive pattern minimizes the ups and downs of variation inherent to biological processes.

A further characteristic is the relatively large volume and monetary value of each batch. Even a small brewery will brew enough to fill over 32,000 bottles in a single kettle full. Kettles are frequently used which will fill more than 150,000 bottles. The retail value of a single brew is often in excess of $45,000. This justifies many measurements of each batch at several points in the process.

Thus it is possible to plot individual values as well as averages computed with several different sub group sizes. Much interpretive data can be milked in this fashion from the volume of statistics and measures which are available. Furthermore, there is ample process time to permit the rehashing of data to gain an insight as to causes for noted variations. Shift differences can be amplified by averaging the brews of each shift together. Or emphasis can be charted to equipment differences when more than one kettle may be used. Material is emphasized if the sub group size corresponds and coincides with the number of brews made from a car of raw material. There is no set pattern for this. The brewer devises his own intervals to best suit his requirements.

Patterns and cycling of the expected variation, when known, can often assist in sharpening performance by revealing causes that are not apparent

from tabulated information. Fig.2 shows typical frequency distribution patterns of several brewery situations. In each drawing the vertical lines represent specifications.

Good control is denoted by A. The distribution is normal and centered on specifications. It could easily apply to specific gravity readings on kettle wort samples. B denotes a dangerous control situation in that the process just fits specifications. E is an extreme situation of this in which limits are exceeded. In either case a realistic examination into specifications may lead to a slacking of requirements - or the process may be sharpened.

C represents the effect of a pair of influences. These may be shift, material or equipment differences. Two peaks are characteristic of a double influence and reasons can usually be found to bring both distributions together and in specifications limits.

D is a process which is in control but out of adjustment. It might refer to diastatic power on malt shipments. Since this is a blended quality discussion with the supplier can correct it. Or it may refer to alcoholic content. In this case a change in conversion schedule is indicated. The fact that most values meet specifications is not enough. This process is capable of operating entirely within desired limits.

F is the type of histogram that results from using measures that are not fine enough. Sometimes the use of a Fahrenheit temperature scale rather than Reaumer will open up a square curve. Such curves often result from rounding off decimals as in reading a long scale short stem hydrometer. Instruments must be capable of detecting the differences which must exist.

G is another curve associated with instrument readings. It shows favoritism to even or whole numbers and is frequently met. If original data is recorded in Reaumer and then transposed to Fahrenheit this type of curve will result.

H cries, "False data" strongly. Rather than admit of values beyond the specification limits the operator reports all over and short readings as on the line. A little instruction on the nature of the normal curve and assurance of no punishment for honest errors will correct these types of histograms.

The chart represented by I results when the number of items is too small to form a recognizable distribution. Interpretable patterns rarely develop on fewer than 15 or 20 individual samples.

J represents a purposeful deletion of part of the product as in sorting by inspection. It would indicate good cooperation on part of a supplier and understanding of the brewers specifications. If, however, the data is supposed to represent all of the product of a process then part of the information has been hidden without any attempt to correct for it.

K indicates a limiting factor for low values and not entirely a normal distribution. It is typical of air content in bottled beer. Minimum values are rarely lowered and skewness to high values is expected.

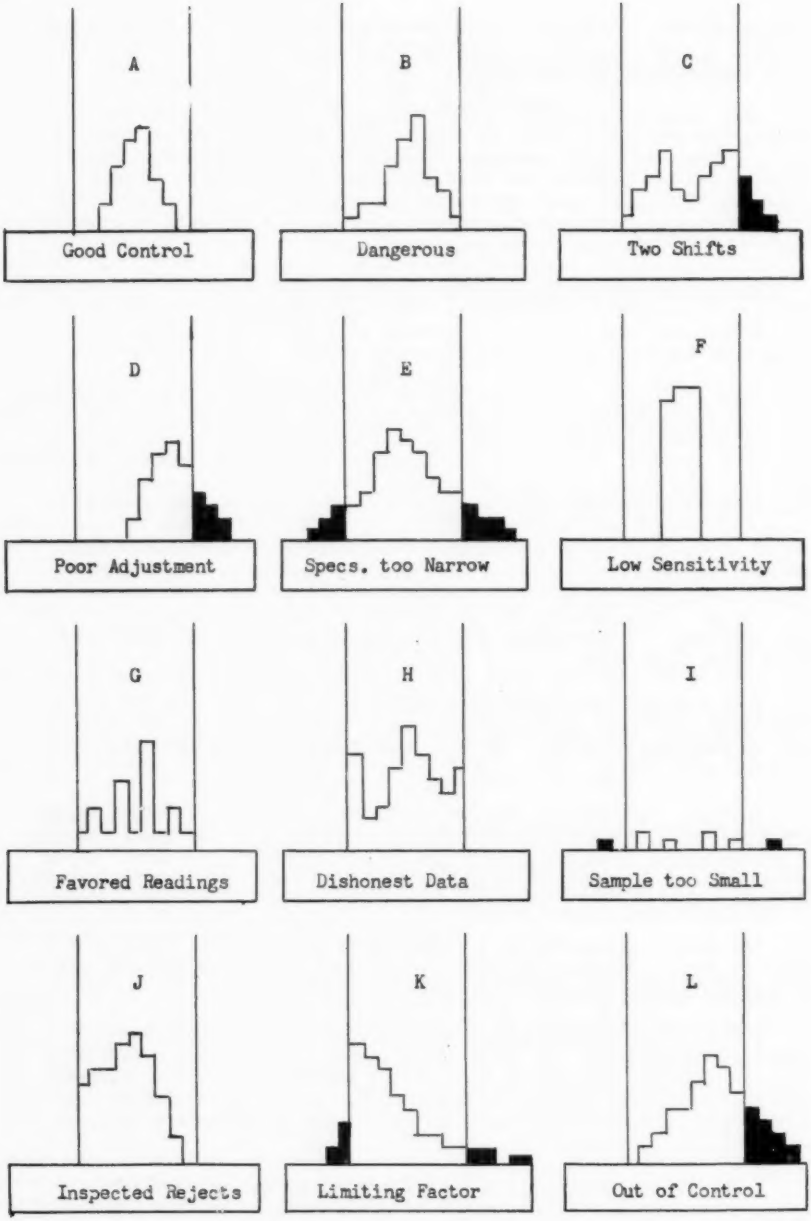

Fig. 2 - Typical Histograms

The histogram depicted by L is typically out of control and out of specification.

Some brewers apply predictive tests at an early stage to give early indications of changes that might occur. The determination of potential amylase activity in barley may thus be correlated to diastatic power of the finished malt. Or the apparent extract following a six hour rapid laboratory fermentation may be correlated with the value found in the plant fermentation from seven to ten days later. If significant changes occur in the predictive tests process alterations may be ordered before more than a few batches are produced. Van der Kloot and Tenney (1) showed how control limits could be drawn around the regression line to determine when differences were significant and uncovered a double factor variation that was not known tc exist in the plant studied.

Analysis of variance with designed experiments are of considerable value in determining the effectivness of or comparing alternate processes. Newmann and Dakin (2) recently discussed this for a filtration problem.

Taste Blending

Quite a number of papers have been devoted entirely to the problem of maintaining statistically uniform flavors. The most recent concerning beer was by Hokansen (3) who described a panel approach to the distinction of differences. Proposed blends are compared to a standard and if the difference cannot be found to a significant degree by a panel of tasters then the blend is accepted for bottling. Obviously these tests are applied after chemical and other quantitative measures have been met. One difficulty with this problem is the lack of permanence to the flavor of the standard. Beer flavor changes after it is bottled or canned and the rate of change depends upon trade conditions. A standard market condition must then be assumed and a moving reference standard is provided by blends that differ with least distinction as the comparing program continues.

One fault of taste panel management is the temptation to ask for preferences. It is folly to seek a preference unless a difference can be firmly established and preference is determined by factors which are not necessarily under consideration. Habit tends to cause favor to that which is familiar. Therefore any test between two beers produced by regular and a proposed alteration to process can fairly ask only, "Is there a difference?" If there is no significant difference the brewer may decide upon the change from purely engineering considerations.

If, however, there is a demonstrable difference and that was due to the process alteration, then the brewer must seek preference opinions from outside his plant. His own employee taste panel will be predjudiced in favor of the standard product. Unfortunately, this is a frequent question and the judgement of even outside market panels is highly questionable.

Market Trends

Overall changes in beer preference on the part of the public are apparent. Today's beer is milder in overall flavor, paler in color, lighter in body and has greater shelf life than was possessed by beers

marketed even five years ago. Perhaps production limitations and competitive advertising campaigns have influenced this trend but the preferences are well established. No thinking brewer would dare aim for any but the middle range and therefore the most voluminous and profitable market. By watching the national and local trends in beer composition and flavor a brewer may keep his product in tune. The superimposition of probability concepts and normal variation upon sales curves of both brewer and competitor can be quite revealing and has helped more than one company improve its competitive position.

The reaction of two different brewers to the adjustment of color intensity in their product is shown in Fig.3. Both brewers were aware of the national average and of each others performance and are direct competitors. Note how one helped reduce the national value and that both came to the same conclusion.

Only the years showing greatest change and demonstrating the industrial trend have been shown. Since 1953 the rate of change has been slower and values of color for all brands is more uniform.

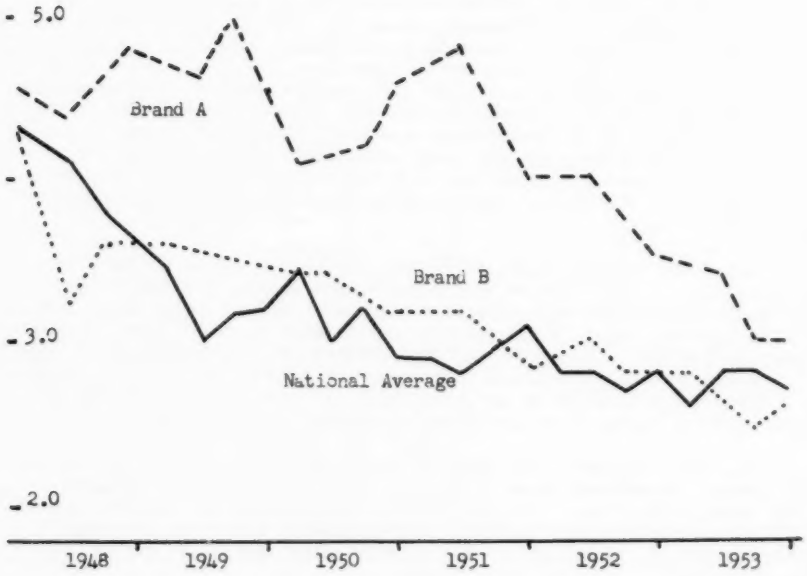

Fig.3 - Change in Color Intensity of Two Brands of Beer Compared to National Average

Shelf-Life and Stability

The prediction of how long a given sample of beer can remain on the market before it changes sufficiently to become objectionable or refused by any particular percentage of the people involves the use of statistical quality control analysis of statistical quality control data. It is, in fact, a multiple use of probability combinations that has been most successful in this area and should probably be classed as operations research rather than Statistical Quality Control. It involves estimating the quantity of any batch remaining on the market as time progresses and estimating the probable amount of average and extreme change in the same time interval.

Packaging

The bottle shop is the most frequent initial application of Statistical Quality Control procedures in a brewery. In part, this is due to the similarity of operations to those of the machine shop and the ready adaption of standardized methods. It is also due to the immediate demonstrable improvement and cost savings that is possible. Control Chart techniques are quite suited to filling operations where amount of product per bottle, the air content and appearance of the package are controllable. Degree of pasteurization, absence of foreign particles, crown tightness, and effectiveness of bottle washing are also considered.

The p chart is applied to the several 100% visual inspections to sharpen this operation. It not only compares effectiveness of the several inspectors but measures the effectiveness of bottle washing equipment and can be used to estimate the quantity of "defective" packages that might be passing the rigid inspections. AQL values below 0.01% are desired for such defects as foreign particles so sampling plans are of little use except to partially assay a days performance.

Beer is shipped generally as soon as it is bottled. No segregation and lot reinspection is possible under the fast and high volume production schedules. Absolute quality with respect to attributes is seldom measured but a brewer can readily get an answer to the question of whether it was at or above any AQL he might wish to assign.

Electronic inspection is replacing visual methods in breweries at this time. Such devices can be set to be more critical than any human and are not subject to fatigue or distractions. The most frequently met objection to these devices is their extreme criticalness. However, the rejects from an electronic inspector may easily be reviewed visually to introduce the element of judgment at far less expense.

Acceptance of SQC

While the adoption of Statistical Quality Control measures has not been universal throughout the brewing industry, there has been no lack of controlled quality. Much of this has been of an intuitive nature which recognizes variation patterns from long experience. The practical brewer has coped with these problems for many centuries and has evolved an attitude towards quality which may well be emulated by manufacturers who believe that SQC will in some magical way improve their quality merely by installing a system. Quality Control is an attitude - not a possession.

At least a fourth of the breweries in the United States and in Canada are using SQC in some phases of their operation. Their plants produce almost half of the beer consumed yet no brewery has reached a point where it considers its program so complete that it cannot be extended and improved. It was a brewer, W. S. Gosset, who wrote under the name "Student" who gave us the t test for significance. (4)

Adoption of the technique since World War II has been rather rapid. There has been no governmental push or requirement - only the competitive impetus to improve. Brewers recognize that Quality Control is an attitude - not a possession. Statistical methods help measure the relative weight of data and sharpen control techniques existing in any process. They contribute to the making of sounder decisions but are not substitutes for decision.

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INTRODUCTION A LA SEANCE D'OUVERTURE
DE LA SESSION FRANCAISE

Julian H. Toulouse
Vice-Président de l'A.S.Q.C.

Les dirigeants de l'Association Américaine pour le Contrôle de la Qualité m'ont pressenti, probablement en raison de mon nom et de ma naissance, pour exprimer leurs compliments et leurs meilleurs voeux à l'occasion de la première présentation d'études techniques, lors de notre Conférence Nationale, en une langue autre que l'anglais.

Je sais que ma connaissance de la langue française laisse à désirer: aussi aurai-je besoin de toute votre indulgence. Le fait que cette session se tienne ici présente pour moi un intérêt tout particulier. En effet, vers la fin du dix-huitième siècle, un membre de la famille du Comte de Toulouse quitta la France quelque peu précipitamment - il ne célébra pas le jour de la Bastille - et fut le premier de mes ancêtres à s'installer en Amérique du Nord: il s'établit à Québec; ultérieurement, la famille émigra dans le Wisconsin, puis dans un petit bourg français de l'Iowa, Marne, où je suis né.

Je trouve que cette première session en langue françai se devrait faire ressortir l'universalité des probabilités statistiques et le caractère international de l'A.S.Q.C.: le langage des Mathématiques est un langage universel auquel de nombreuses personnes ont contribué. Les "Lois du Hasard" ne sont pas édictées par l'Homme, elles ne connaissent pas de frontières nationales.

L'A.S.Q.C. est internationale; en effet, ses sections locales sont organisées au Japon, au Mexique, au Canada et aux Etats-Unis. Environ deux pour cent (2%) de ses membres proviennent d'autres pays encore. On pourrait fort bien l' appeler l'Association Interaméricaine pour le Contrôle de la Qualité.

Le petit groupe des membres fondateurs de l'Association comprend quatre Canadiens: MM.Gillis, Gnaedinger, Lloyd et Westman. Ces quatre membres, ainsi que MM. Allan et Lessard, se sont vu attribuer le titre de "Fellow". La section de Toronto fut organisée au cours de la première année de l' Association; vinrent ensuite celles de Montréal, Western Ontario, Windsor et Hamilton. On comprend ainsi le rôle important joué par le Canada au sein de l'Association.

Je voudrais mettre en évidence les contributions très importantes apportées à la Science des Statistiques par des personnalités de langue française auxquelles je voudrais marquer mon respect en les citant ainsi que quelques-uns de leurs ouvrages. Je tiens à le faire car nous sommes encore trop nombreux à penser que seuls ont contribué à cette Science ceux qui ont écrit en notre propre langue, Pour ceux d' entre nous qui ne parlent que l'anglais, nous connaissons les

noms de Shewhart, Simon, Dodge, Workman, Olds, Westman et Romig, mais nous ne connaissons pas aussi bien ceux de Darmois, Mothes, Delaparte, Cave ou Vessereau. Nous semblons oublier que les savants français: de Moivre, Laplace, Pascal et Bernouilli ont établi les fondements mêmes des probabilités statistiques.

Pour présenter ce tableau d'une façon plus nette, passons d'abord en revue quelques noms des dix-septième au dix-huitième siècle:

- Blaise PASCAL, ce grand savant qui étudia la Science des jeux de Hasard, et découvrit vers seize cent quarante (1640) le Calcul des Probabilités.

- Jacques BERNOUILLI publia vers dix sept cent treize (1713) "Ars Computandi", ouvrage de base qui donne la Loi des Grands Nombres.

- Antoine de Moivre écrivit en dix sept cent dix-sept (1717) une analyse des Jeux de Hasard en français et en anglais, qui constitue le résumé des connaissances, à cette date, sur l'application du Calcul des Probabilités aux jeux de carte.

- Laplace publia en dix huit cent douze (1812) sa "Théorie Analytique des Probabilités"; ce fut là son oeuvre magistrale, source de tous les développements ultérieurs.

- Quételet, son successeur, pose les bases d'une théorie du comportement humain de l'homme moyen; chaque homme se définit alors par rapport à cet homme moyen par des variations en plus ou en moins, qui sont aléatoires, et donc relèvent du Calcul des Probabilités.

Dans la France contemporaine, un autre groupe de personnalités gagneraient à être mieux connues ici:

- G.Darmois, professeur à la Sorbonne et Président de l'Institut International de Statistiques, qui a écrit une longue série d'articles tant scientifiques que pratiques; parmi ses publications, pour illustrer la durée de sa contribution à la Science, citons " Statistique Mathématique" de dix neuf cent vingt-huit (1928) et " Colloque International d'Analyse Factorielle" de dix neuf cent cinquante-cinq(1955).

- Jean Mothes, Ingénieur au Gaz de France et Secrétaire Général de l'Institut de Statistiques de l'Université de Paris, qui a fait beaucoup dans le domaine des applications industrielles. Parmi de nombreuses études, citons par exemple ses "Principes Fondamentaux de la Méthode Statistique et Applications Industrielles" publiés dans la "Revue de Statistique Appliquée " en dix neuf cent cinquante quatre et cinquante cinq (1954 et 1955).

- P.Delaporte, Professeur à l'Institut de Statistiques de l'Université de Paris, qui en plus de nombreux ouvrages

parus, a trouvé nombre d'applications des méthodes statistiques à la recherche industrielle.

- R. Cave, Ingénieur Militaire Principal de l'Armement, dont les plus importantes publications ont trait au contrôle statistique de fabrication; c'est d'ailleurs le titre de son ouvrage publié en dix neuf cent cinquante-trois (1953) et le thème général de ses diverses études parues dans la "Revue de Statistique Appliquée".

- A. Vessereau, Ingénieur en chef des Manufactures de l'Etat, dont les "Methodes Statistiques en Biologie et Agronomie" en dix neuf cent quarante-huit (1948) sont à l'origine des méthodes qui se révélèrent très utiles, non seulement dans les domaines cités plus haut, mais également dans la recherche industrielle.

Cette énumération n'est pas complète et sert seulement à délimiter le domaine des travaux. Mentionnons maintenant des auteurs canadiens dont les ouvrages nous sont mieux connus:

-A.E.R. Westman, Directeur du Département de Chimie du Centre de Recherches de l'Ontario, est l'auteur d'un grand nombre d'études statistiques. Il fonda la Section de Toronto de l'A.S.Q.C. et fait partie du comité E-II de l'Association Américaine pour l'Essai des Matériaux. Ses études comprennent chimie, métallurgie, céramique, peinture, fonderie, plans expérimentaux et cartes de contrôle.

- Herbert Marshall, qui fut autrefois à la tête du Bureau des Statistiques du Dominion, et ancien Président de l'Association Américaine de Statistiques.

- E.S. Keeping, Université d'Alberta, qui fut dans l'enseignement des Statistiques pendant de nombreuses années et qui nous a donné plusieurs étudiants de valeur.....

- J.W.Hopkins, de la Division de Biologie Appliquée au Conseil National de la Recherche, dont l'influence en matière de Statistiques se ressent au travers de tous les Services Gouvernementaux.

- C.H. Goulden, auteur de l'un de nos livres scolaires, et l'un des premiers Canadiens à découvrir l'importance des idées nouvelles en matière de plans expérimentaux.

- D.F. Brown, introduit un programme de contrôle de qualité dans une usine de munitions de guerre vers dix neuf cent quarante (1940) et publie en dix neuf cent quarante-quatre un rapport dans " Industrial Quality Control".

- J.Mc. Keigan mit en route un programme de contrôle de qualité dans une Manufacture d'Armes pendant la guerre. Il contribua également dans une large mesure à la constitution de la Société de Contrôle de Qualité de Toronto qui devint par la suite la Section de Toronto de l'A.S.Q.C.

- H.H. Fairfield, du Bureau des Mines, porta ses efforts sur les Méthodes de Contrôle dans les opérations de fonderie. En dix neuf cent quarante-deux (1942), il publia sur ce sujet: " Méthodes Statistiques appliquées au contrôle des opérations de fonderie, travaux de l'Association Américaine de Fonderie, Volume cinquante (50).

Ainsi, ces sessions françaises donnent l'occasion, non seulement de reconnaître l'importante contribution de la France et du Canada à la Science statistique, mais également de souligner l'aspect international de l'A.S.Q.C.

En faisant honneur aux autres, l'Association s'honore.

INTRODUCTION TO THE FIRST MEETING OF THE FRENCH SESSIONS

Julian H. Toulouse
Vice-President, A.S.Q.C.

The officers of the American Society for Quality Control, probably because of my name and ancestry, have asked me to convey their greetings and best wishes at this first occasion when technical papers are being presented in our national convention in a language other than in English.

I know that my knowledge of French leaves much to be desired - I ask all your indulgence. To be here has a special interest because the first of my family in North America, of the family of the Count of Toulouse, left France rather hurriedly in the 1790's - he did not celebrate Bastille Day - and was the first of my family to settle in North America. The family later migrated to Wisconsin, and I was born in a little French community, Marne, in Iowa.

I think this first French langauge session serves to emphasize the universal character of the statistics of probability and the international character of A.S.Q.C. The language of mathematics is a universal language to which many people have contributed. The "laws of chance" are not man-made laws - they recognize no national boundaries.

A.S.Q.C. is international because its members and its local sections are organized in Japan, Mexico, Canada and the United States. About two percent (2%) of its members came from still other countries. It might well be called - "The Inter-American Society for Quality Control".

The small group of founding members of the Society include four Canadians: Messrs. Gillis, Gnaedinger, Lloyd and Westman. These four members in addition to Messrs. Allan and Lessard, are "Fellows" of A.S.Q.C. The Toronto Section was organized during the first year of the society, followed by Montreal, Western Ontario, Windsor and Hamilton. Thus, Canada plays an important part in the Society.

In considering the significance of these French language sessions, we note the very great contributions of French speaking people to the science of statistics. Let us first pay our respects to them by mentioning their names and some of their work. I wish to do this because altogether too many of us are inclined to believe that the people who write in one's own language are the only ones who have contributed to the subject. We, who habitually speak only English, know the names of Shewhart, Simon, Dodge, Workman, Olds, Westman and Romig, but do not know equally the names: Darmois, Mothes, Delaparte, Cave or Vessereau. We forget that the French savants: de Mauvre, La Place, Pascal and Bernouilli, made the very foundation of the statistics of probability.

To make the record clear, first consider these men from the 18th and 19th centuries:

Blaise Pascal, that great scientist, who discovered the calculus of probability about 1740.

Jacques Bernouilli whose "Ars Computondi" in 1713 established the "Great Numbers Law".

Antoine de Mauvre, whose work in the doctrine of chances in 1717 summarized the knowledge of that day on the application of the calculus of probability to games of cards.

La Place, whose great work "Analytic Theory of Probability", in 1812 was the source of all later developments.

Guetelet, his follower, established the basis of a theory of the condition of the average man. Each man follows the average man, with variations more or less, and in agreement with the mathematics of probability.

In present-day France, another group of men should be better known here:

G. Darmois, Professor at the Sarboune and the President of the International Institute of Statistics, who has written a long list of articles, both scientific and in practical application. Of the many publications, let us list, "Statistique Mathematique", of 1928, and "Colloque International d'Analyse Factionalle", of 1955 just to show the long period of contribution to the science.

Jean Mothes, Ingenier au Gaz de France, and Secretary General of the Institute of Statistics of the University of Paris, who has done much in the field of industrial application. Of many papers, let us list, for example, his Fundamental Principals of the Statistical Method and Industrial Application, from the Revue de Statistique Applique, in 1954 and 1955.

P. Delaporte, Professor at the Institute of Statistics of the University of Paris, who, in addition to published works, has made a large number of applications of the statistical method to industrial research.

R. Cave, Principal Military Engineer of Armament, whose major publications are concerned with "The Statistical Control of Manufacture", which was the title of his book in 1953, and the general theme of his several papers in the "Revue de Statistique Applique".

A. Vessereau, Chief Engineer of State Manufactures, whose "Methods Statistiques en Biologie and Agronomie", in 1948, developed methods which were very useful in industrial research not confined to the sciences listed in the title.

This list is not complete and serves only to outline the field of work. Now to list Canadian authors whose work is better known to us:

A. E. R. Westman, Director of the Department of Chemistry of the Ontario Research Foundation, is the author of a large number of statistical studies. He was a founder of the Toronto Section of A.S.Q.C. and a member of Committee E-11 of A.S.T.M. His studies include chemistry, metallurgy, ceramics, paint, foundry, experimental design, and control charts.

Herbert Marshall, former head of the Dominion Bureau of Statistics and past president of the American Statistical Association.

E. S. Keeping, of the University of Alberta, who has been teaching statistics for a good many years and has given us many distinguished students.

J. W. Hopkins, of the Division of Applied Biology, National Research Council, whose statistical influence is felt throughout the government service.

C. H. Goulden, author of one of our standard textbooks and one of the first men in Canada to perceive the importance of the new ideas on experimental design.

D. F. Brown who introduced a quality control program in an ammunition plant about 1940, and published a report on this in Industrial Quality Control in 1944.

John McKeigan started a quality program in a small-arms plant during the war. He contributed in a large way to the establishment of the Toronto Control Society, which became the Toronto Section of A.S.Q.C.

H. H. Fairfield, of the Bureau of Mines worked on methods of control in foundry operations. He published "Statistical Methods as an Aid to the Control of Foundry Operations" in the Transaction of the American Foundrymen's Association, Vol. 50, 1942.

Thus, these French Language Sessions not only give opportunity to recognize the great contributions to statistics in France and Canada, but also to recognize the international aspect of A.S.Q.C. In honoring others, the Society honors itself.

RIQAP—A NEW APPROACH TO PRODUCT EVALUATION

Philip Reiter
The Army Signal Supply Agency

What is RIQAP?

It is the "Reduced Inspection Quality Assurance Plan" developed and applied by the Signal Corps. In RIQAP, maximum recognition is given to the contractor who consistently maintains a high level of product quality. There is a sharp reduction of Signal Corps product inspection. In its place there is regular, but unscheduled, appraisal of the contractor's quality control and inspection systems and records, with a minimum of product inspection using newly developed statistical techniques. RIQAP is a voluntary plan and is installed only upon agreement between the contractor and the Signal Corps.

Basic Requirements for RIQAP

The contractor must have:

(1) A record of high quality of production.

(2) An effective quality control and inspection system.

Qualification of a Contractor

(1) Qualifying Experience: There must be a record of production with a process average equal to or better than the Acceptable Quality Level (AQL). Appropriate records of one or more of the following types may be considered as qualifying experience:

(a) Current Signal Corps inspection of the specific item under consideration.

(b) Current Signal Corps inspection of a similar military item.

(c) Contractor inspection records for commercial production of an identical or similar product (this experience may be substituted only on a partial basis).

(2) Quality Control and Inspection System: For continuing assurance of a high level of product quality, the contractor's quality control organization must have an effective voice in management. Pressures from production must not be permitted to prevent or delay corrections necessary to maintain quality. The quality control and inspection system must exhibit in-process control of either an inherent or a statistical nature. But, as a most important feature, there must be an effective feedback of inspection data for positive and rapid corrective action in the process. Figure 1 illustrates in flow diagram form the most desirable, the minimum qualifying, and the unacceptable systems for RIQAP.

(3) Record System: The usual records maintained and furnished under regular Signal Corps sampling inspection are normally sufficient for RIQAP. Expansion of records is not required unless their absence will substantially affect the evaluation of product quality. Basically, the record system must be accurate, up to date, and used to control or improve the quality of the product. Figure 2 illustrates record systems considered most desirable, minimum acceptable, and unacceptable.

Preliminary Steps in the Installation of RIQAP

(1) Applicability:

(a) RIQAP may be introduced on a partial basis, for individual qualifying production lines, items, departments, floors, etc. or on a plant-wide basis.

(b) When RIQAP is installed on a partial basis, the plant may gradually work into full operation as each segment qualifies. This allows for a gradual change in overall quality control and inspection techniques

QUALITY CONTROL AND INSPECTION SYSTEMS

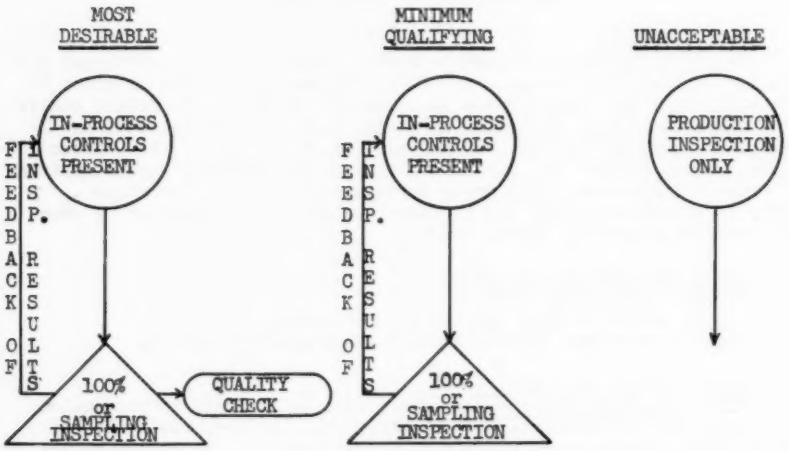

Figure 1.

RECORD SYSTEMS

MOST DESIRABLE	MINIMUM ACCEPTABLE	UNACCEPTABLE
CONTROL CHARTS ON ALL PROCESSES. FINAL INSPECTION DATA. TREND INDICATION DATA SUCH AS: SUMMARY RECORDS QUALITY AUDITS VENDOR QUALITY RATINGS ETC.	PROCESS RECORDS TREND INDICATION DATA SUCH AS: CONTROL CHARTS SHRINKAGE REPORTS ATTRIBUTE SUMMARIES ETC.	NO RECORDS or INDIVIDUAL RECORDS WITH NO TREND INDICATION

Figure 2.

where necessary.

(2) Development of Candidates: Prospective candidates develop from:

(a) Recommendations by Signal Corps personnel familiar with the contractor's operation.

(b) Contractor's request for consideration.

(3) Basic Review of Qualifications:

(a) Since RIQAP is a voluntary plan, the details of its operation are explained to the prospective candidate and his concurrence for possible installation is obtained before further action is taken.

(b) Then careful study is made to insure that he meets minimum requirements with respect to: quality history for his product, his quality control and inspection system, and his record system.

(4) Contractor's Inspection and Quality Control Plan: A basic requirement in RIQAP is the preparation of a written plan covering the quality control and inspection operations of the plant, or segment thereof, under consideration. This plan must encompass the procedures which will be followed after installation of RIQAP. Whereas no specific method is prescribed for the preparation and reproduction of the plan, a suggested format has been published and is available as to its required content. Responsibility for content must obviously rest with the contractor, but all practical assistance and cooperation is offered by the Signal Corps in the preparation of the written plan.

Installation Actions

(1) Formation of the Technical Group: Upon satisfactory completion of preliminary steps, a Technical Group is formed to fully evaluate the contractor's qualifications for RIQAP and to accomplish its installation. The Technical Group is composed of a team, staff and operating Signal Corps personnel especially trained in all aspects of RIQAP. Included are Quality Control Specialists, Equipment Specialists, and operating inspection personnel.

(2) Preliminary Survey: Prior to the overall evaluation by the full Technical Group, a preliminary survey is conducted by the Chairman of the Group. This action is taken so that obviously weak or questionable points may be resolved with the contractor with a minimum loss of time before the final survey.

(3) Final Survey: The entire Technical Group participates in the final survey. This survey is accomplished by a visit to the facility.

(a) Records Review: Initially, Signal Corps inspection records are carefully reviewed for the product under consideration. Notes are made so that particular attention may be given to any questionable areas during the tour of the plant.

(b) Process Review: All areas concerned with the product under consideration are then visited. This includes all positions and processes from incoming inspection through the final packing and shipping. A comprehensive check list is used to guide the technical group in this survey. Notes on questionable points are recorded for later discussion and resolution at a conference with the contractor.

(4) RIQAP Conference

(a) At this conference, the findings of the Technical Group are presented to the contractor. Recommended changes in procedures required for qualification are discussed in an effort to adjust or resolve them, or consider counter-proposals.

(b) A mutually agreeable date is arrived at for the installation of RIQAP.

(c) A full review is made of the salient features of RIQAP, including such matters as the procedure for removal from RIQAP and requalification, and the nature of Signal Corps operation under this plan.

Operation under RIQAP

After qualification of the contractor for RIQAP, the Technical Group prepares written procedures covering Signal Corps operation under the plan. The Signal Corps performs a sharply reduced amount of product inspection, and obtains assurance of quality largely from a regular review of the contractor's inspection and quality controls, as follows:

(1) Check of Inspection and Quality Control Systems: At periodic, but non-routine, intervals the plant is surveyed to assure proper exercise of controls, control of processes, performance of required inspection, etc. If unacceptable, but not seriously deficient performance is noted, corrective action is requested with a reasonable period allowed. Where serious deficiencies are found, immediate action is taken to avoid acceptance and shipment of the material.

(2) Analysis of Records of Inspection: Also at periodic, but non-routine, intervals a review is made of the contractor's inspection records for matters such as: accuracy, applicability, process variability, quality trends, disposition of material, discrepancies, etc. Where poor quality or a trend towards poor quality is found, additional checks are made of positions involved. In addition, the contractor is advised and corrective action requested. Where deterioration of quality is sudden and serious, action is taken to remove the position from RIQAP.

(3) Signal Corps Product Inspection: Under RIQAP, Signal Corps inspection which was formerly conducted on a lot-by-lot basis is now conducted on a sharply reduced basis using one of the following techniques:

(a) Skip-lot Sampling Plan (See Appendix 1).

(b) Multi-level Continuous Sampling Plan (See Appendix 2).

The most common method applied is the Skip-lot Sampling Plan. Where, however, the lots consist of very few units, the Multi-level Continuous Sampling Plan is used.

(4) Removal from RIQAP: If the contractor's control of quality deteriorates, he is advised and, provided that this deterioration does not seriously affect the outgoing quality, he is given a reasonable period for correction. If correction is not achieved in the time allowed, the position is removed from RIQAP and returned to lot-by-lot inspection with tightened sampling.

(5) Requalification

(a) After loss of Control: A process can be requalified for RIQAP when conditions causing the loss of control have been positively corrected. This can be established by a reasonable period of quality with process average better than the AQL.

(b) After Production Stoppage: No requalification is required after production stoppage which is brief. Intermediate lengths of production stoppage will require increased frequency of Signal Corps product inspection. Long stoppages will require complete requalification.

Advantages of RIQAP to Contractor: The following are some of the advantages which accrue to the contractor who operates successfully under RIQAP:

(1) Smoother and more rapid production flow.

(2) Minimum delay due to Signal Corps product inspection.

(3) Less storage space for product pending inspection.

(4) Signal Corps inspection procedures tailored to the specific operation.

(5) Minimum increase in testing equipment for Signal Corps as production increases.

(6) Normally, no increase in record keeping.

(7) Improved understanding between contractor and Signal Corps through better knowledge of each other's problems and obligations.

(8) Use of RIQAP on a limited initial basis for qualified departments or lines.

(9) Improved employee morale through public recognition of their past in producing quality product.

(10) Official Signal Corps recognition to the plant for quality production.

Problems and Prospects for RIQAP

Although RIQAP has been in operation in the Signal Corps for well over two years, there still is a long way to go. Many more contractors can and will qualify. New techniques are under study for further improvement of the present scientific basis for reduced inspection procedures which will still give necessary protection to the customer—the Signal Corps—and yet reduce to the minimum the extent of product inspection required. In RIQAP, the Signal Corps has met the challenge: to recognize the quality producer and yet maintain full protection of its quality requirements.

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APPENDIX I

OPERATION OF SKIP LOT SAMPLING PLANS

The frequency and level of sampling in the Skip Lot Sampling Plan operates on the basis of three action limits, thus giving four areas of operation. These limits are represented by figures APP-1A and APP-1B for Group A and Group B Tests.

The following definitions apply to differentiate the attributes examined at each of these positions:

Group A Tests. Group A Tests are tests of workmanship and electrical and mechanical characteristics which are subject to variability due to production. Failures in this test group will usually result in failure of the unit to perform its intended function. Generally, complex inspection facilities are not required, the tests are non-destructive, and are of short duration.

Group B Tests. Group B Tests are tests of characteristics that are basically fixed by design and are affected very little by production. Failures in this test group will always affect the serviceability of the item by reducing effective life or hindering performance, but will not necessarily result in inoperatives or a completely non-useful life. Generally, these tests require complex inspection facilities, are moderately lengthy, and may be destructive.

ACTION LIMITS FOR PROCESS AVERAGE

GROUP A INSPECTION

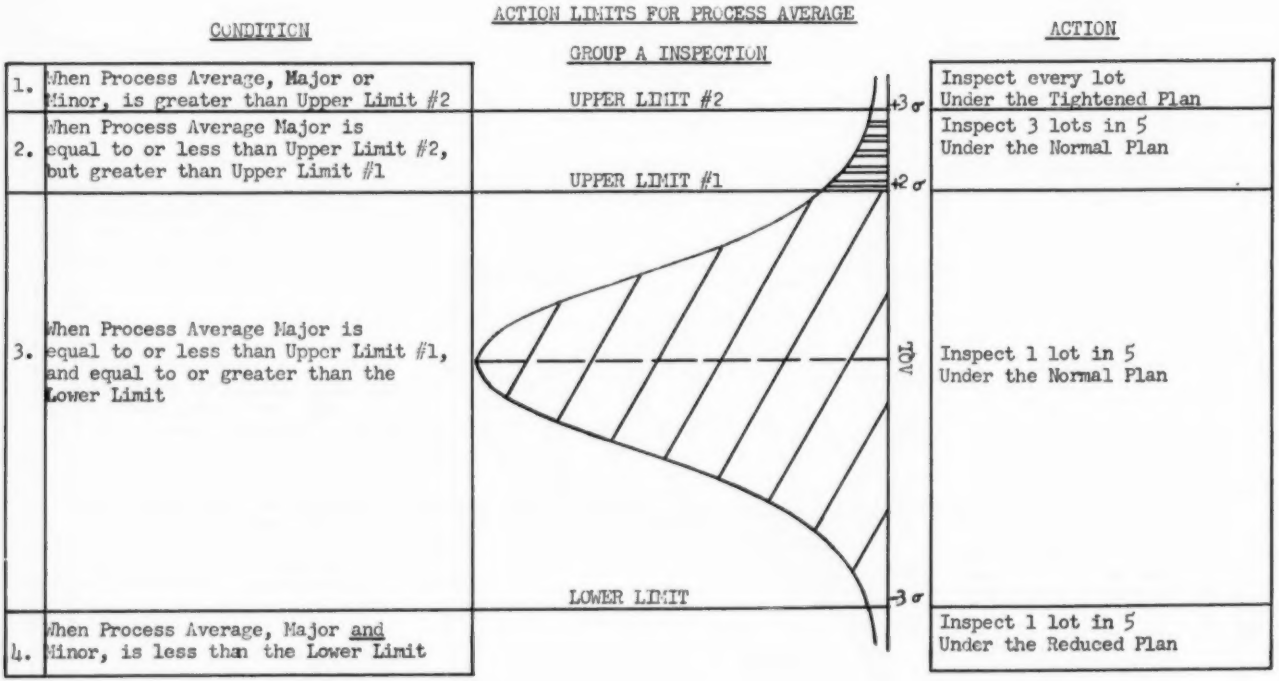

CONDITION
ACTION
1. When Process Average, Major or Minor, is greater than Upper Limit #2
2. When Process Average Major is equal to or less than Upper Limit #2, but greater than Upper Limit #1
3. When Process Average Major is equal to or less than Upper Limit #1, and equal to or greater than the Lower Limit
4. When Process Average, Major and Minor, is less than the Lower Limit
UPPER LIMIT #2
UPPER LIMIT #1
AQL
LOWER LIMIT
+3 σ
+2 σ
-3 σ
Inspect every lot Under the Tightened Plan
Inspect 3 lots in 5 Under the Normal Plan
Inspect 1 lot in 5 Under the Normal Plan
Inspect 1 lot in 5 Under the Reduced Plan

Figure APP-1A

ACTION LIMITS FOR PROCESS AVERAGE
GROUP B TESTS

CONDITION		ACTION
1.	When Process Average is greater than Upper Limit #2	Inspect every lot under Tightened Plan
2.	When Process Average is equal to or less than Upper Limit #2, and greater than Upper Limit #1	Inspect 1 Lot in each 3 under Normal Plan
3.	When Process Average is equal to or less than Upper Limit #1, and equal to or greater than Lower Limit	Inspect 1 Lot in each 5 under Normal Plan
4.	When Process Average is less than Lower Limit	Inspect 1 Lot in each 5 under Reduced Plan

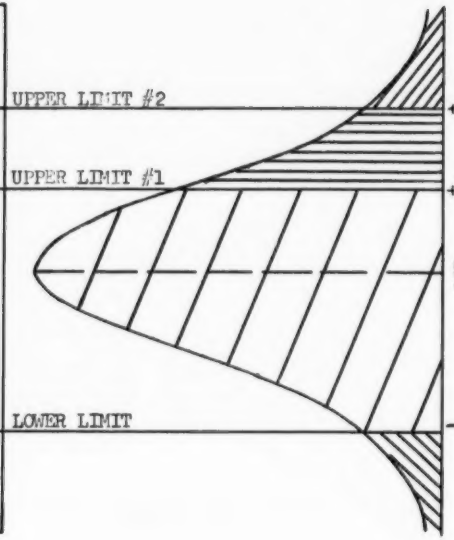


Figure APP-1B

APPENDIX II

OPERATION OF MULTI-LEVEL CONTINUOUS SAMPLING PLANS

The operation of any multi-level continuous sampling plan is dependent on the two factors i and f. i is the clearance number. For a given AOQL, i is a constant which governs the number of consecutive units which must be found free of defects on 100% inspection and the number of sample units which must be found free of defects at each step in the plan before reducing inspection to the next step. f is the frequency of sampling. For a given AOQL, f is a variable fraction (1/2, 1/3, etc.) which governs the rate of sampling at each step in the plan.

The five steps described below are an example of a four level continuous sampling plan:

Step. (1) 100% inspection is performed on the units, in the order of their production, until i consecutive units are found free of defects. When i units are found free of defects;

Step (2) Sampling inspection is performed at the frequency f, until i units have been found free of defects. If a defect is found before i units have been inspected, return to STEP (1). When i units are found free of defects at frequency f;

Step (3) Inspection is performed at the frequency f^2 until i units have been found free of defects. If a defect is found before i units have been inspected, return to STEP (2). When i units are found free of defects at frequency f^2;

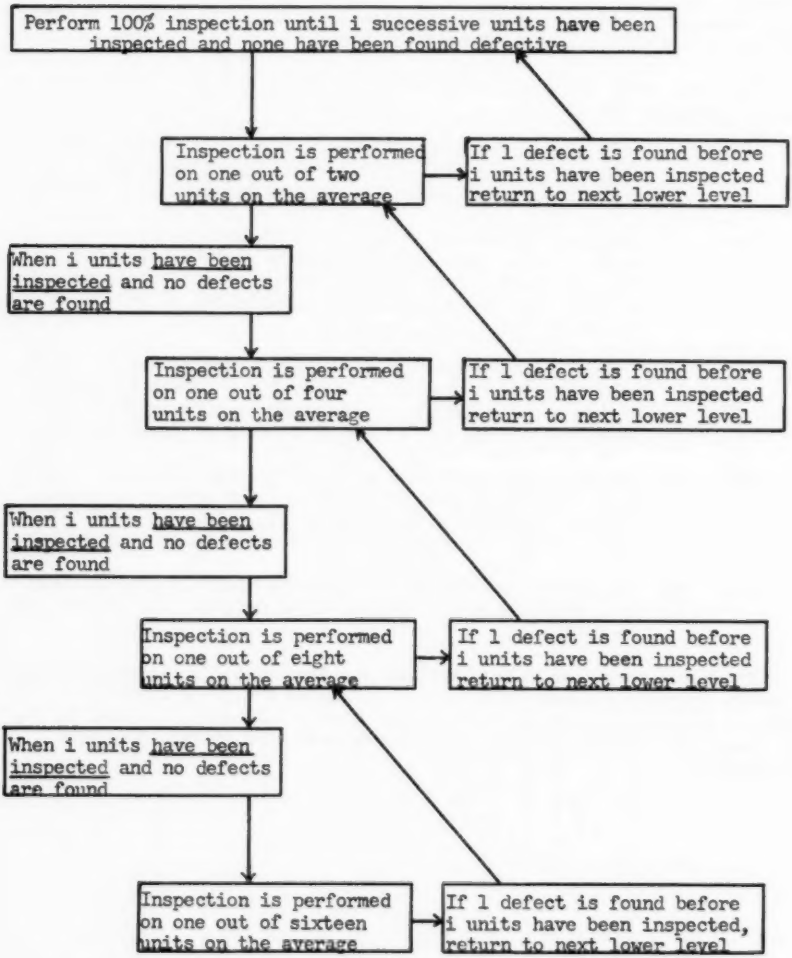
Step (4) Inspection is performed at the frequency f^3 until i units have been found free of defects. If a defect is found before i units have been inspected, return to STEP (3). When i units are found free of defects at frequency f^3;

Step (5) Inspection is performed at the frequency f^4 indefinitely or until a defect is found. If a defect is found, return to STEP (4).

The above four-level plan stops at the frequency f^4. Theoretically, however, continuous sampling plans can reduce to f^∞. The following chart is an example of a four-level plan with a 2.0% AOQL, i equal to 30, and frequency f equal to 1/2. The maximum reduction at f^∞ is one unit in sixteen.

OPERATION OF A FOUR-LEVEL CONTINUOUS SAMPLING PLAN

AOQL 2%


Perform 100% inspection until i successive units have been inspected and none have been found defective
Inspection is performed on one out of two units on the average
If 1 defect is found before i units have been inspected return to next lower level
When i units have been inspected and no defects are found
Inspection is performed on one out of four units on the average
If 1 defect is found before i units have been inspected return to next lower level
When i units have been inspected and no defects are found
Inspection is performed on one out of eight units on the average
If 1 defect is found before i units have been inspected return to next lower level
When i units have been inspected and no defects are found
Inspection is performed on one out of sixteen units on the average
If 1 defect is found before i units have been inspected, return to next lower level

Where i = Clearance Number 30

STATISTICAL METHODS FOR DETERMINING OPTIMUM CONDITIONS

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The article that follows is perhaps over long. It contains however a brief description of the new experimental designs and methods of statistical analysis originally proposed by Dr. G. E. P. Box of Imperial Chemical Industries. These statistical tools are having a profound effect upon research, development and production studies in the chemical, metals and textile industries. It is the purpose of this article to describe briefly some of the new experimental designs, and to employ occasional simple numerical examples to illustrate the methods of analysis. Detailed descriptions and examples can be found in part in the book The Design and Analysis of Industrial Experiments edited by O. L. Davies and in the literature cited in the bibliography.

One Dimensional Experimental Designs

Oftentimes an experimenter is interested in exploring the relationship between some response y as a continuous function of some single quantitative variable x, the variable x being under the control of the experimenter. For example the response y may be the yield of some chemical process while the controlled variable x the length of time of the reaction. Such studies, requiring the control of but one single variable, give rise to what are termed 'one dimensional' experimental designs.

Initially nothing may be known about the nature of the relationship; the variable y being simply an unknown function of x, i.e.,

$$y = f(x) . \qquad (1)$$

As a first step in exploring this association between y and x it is frequently assumed that the response y is a simple straight line function of x. The mathematical model expressing this linear relationship can be written as

$$y = \beta_0 + \beta x \qquad (2)$$

where β_0 is the intercept of the fitted line on the y axis, and β is the slope of the line. The choice of this linear model may be based on the knowledge of analogous experimental studies, or may simply be the knowledge that quite complicated functions can be illustrated by straight lines over limited ranges. Estimates of the coefficients β_0 and β can be quickly obtained using least squares. The actual least squares formulas for estimating these coefficients are given in many texts (1,2,3) and are quite easy to use.

After the straight line model has been fitted to the data it may be apparent that it inadequately represents the relationship between y and x. Also, it frequently happens that the experimenter knows beforehand that a straight line is an inadequate approximation to the unknown function and he may wish from the very start to fit a quadratic curve to the data, i.e. fit the second order mathematical model

$$y = \beta_o + \beta_1 x + \beta_{11} x^2 \qquad (3)$$

Estimating the coefficients in this model by least squares is straightforward, but can become very cumbersome numerically. The calculations are particularly difficult if the response y has been recorded at some haphazard array of settings of the controlled variable x. To reduce this computational load it is usually requested that the response be recorded at equally spaced intervals of the controlled variable. This simplest of experimental designs then permits the rapid estimation of the coefficients in the second order model through the use of the Orthogonal Polynomials (4,5). In fact by using the tables of the orthogonal polynomials the fitting of a cubic or quartic model is similarly very simple provided of course that the suggestion of observing y at equally spaced intervals of x is followed.

Since only one variable is controlled, x, these simple arrays of settings for x are all called one dimensional experimental designs. The order of the experimental designs however, depends upon the order of the mathematical model to be fitted. Obviously, the minimum number of points in these designs always equals the number of coefficients needed to be estimated in the mathematical model. Thus a third order, one dimensional experimental design is provided by four equally spaced settings of the controlled variable x. The resultant four observations will then supply the information necessary to estimate the four coefficients in the third order mathematical model

$$y = \beta_o + \beta_1 x + \beta_{11} x^2 + \beta_{111} x^3 \qquad (4)$$

Of course it is usually very wise not to use a one dimensional design with the minimum number of points. Good practice dictates that several more than the minimum number of settings of the controlled variable be used and that some or all of these points be repeated. Repeating experimental points provides the experimenter with a valid estimate of his experimental error. Additional settings of the controlled variable, coupled with a measure of the experimental error, provide the experimenter with a measure of the "lack of fit" of the mathematical model.

First Order Designs

Two Dimensional First Order Designs

Frequently an experimenter may be interested in studying some response variable as a function of two independent controlled variables, i.e.,

$$y = f(x_1, x_2) \qquad (5)$$

For example the response variable y may again be the yield of a chemical process while the controlled variables x_1 and x_2 are the time and temperature of the reaction. As in the one dimensional case, the first step in exploring this function may be to fit the first order model

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 \qquad (6)$$

This mathematical expression is the equation of a plane.

If the response y is recorded at a haphazard array of settings of x_1 and x_2, the estimates of the coefficients in the model can become quite awkward. However, if the experimenter will pre-select the settings of x_1 and x_2, that is, use an experimental design, not only will the calculations be greatly reduced, but the experimenter's confidence in all of the estimated coefficients can be made constant.

The most popular experimental design for fitting this planar model is the two level factorial design. This experimental design requires that each controlled variable be fixed throughout the experimental program at a high level and at a low level, and that all possible combinations of high and low levels of the variables be run. For example, suppose an experimenter were planning to study the relationship between the expected yield of a chemical process as a function of time and temperature. A two level factorial design would take the form:

Controlled Variable Levels		Experimental Design Levels		Response	Predicted Response
Time	Temp.	x_1	x_2	y	y
1 hr	240°C	-1	-1	43	42
5	240	1	-1	53	54
1	280	-1	1	59	60
5	280	1	1	73	72

The mathematical model is most conveniently fitted to the experimental design levels rather than the actual levels of time and temperature. The coding mechanism associating the design variables x_1 and x_2 with time and temperature are:

$$x_1 = \frac{\text{Time in hours} - 3}{2}, \quad x_2 = \frac{\text{Temp } ^\circ\text{C} - 260}{20}.$$

The estimates of the coefficients in the planar model given in (6) are:

$$b_o = \frac{43+53+59+73}{4}, \quad b_1 = \frac{-43+53-59+73}{4}, \quad b_2 = \frac{-43-53+59+73}{4}.$$

The fitted equation is then

$$\hat{y} = 57 + 6x_1 + 9x_2 .$$

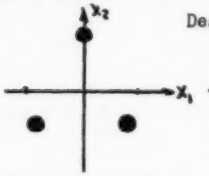
The method for computing these coefficients is quickly recognized. The four predicted values of the responses are recorded in the table above. The resultant regression analysis table (or analysis of variance table if you insist) is

		df
Total Corrected Sum of Squares	472	3
A Effect	144	1
B Effect	324	1
Residual Sum of Squares	4	1

As a check we note that the sums of squares of the differences between the observed and predicted values of the response

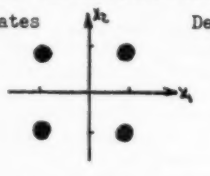
$\sum_{i=1}^{4} (\hat{y}_i - y_i)^2$, equals the residual sum of squares.

If the settings of the design variables are plotted out on a set of coordinate axes labeled x_1 and x_2 they will form the vertices of a square. Another experimental design, called a first order experimental design, that will also quickly provide estimates of the coefficients in the model is formed from the vertices of an equilateral triangle. These two designs are illustrated below



Design Coordinates	
x_1	x_2
$-\frac{6}{2}$	$-\frac{2}{2}$
$\frac{6}{2}$	$-\frac{2}{2}$
0	2

1st Order Design
"Equilateral Triangle"



Design Coordinates	
x_1	x_2
-1	-1
1	-1
-1	1
1	1

2^2 Factorial Design

First Order Experimental Designs: Three or More Dimensions

Situations in which some response may be the function of three or more controlled variables are not at all uncommon, i.e.,

$$y = f(x_1, x_2, x_3, \ldots, x_k) \qquad (7)$$

The first order model in three dimensions is a simple extension of equations (2) and (6), i.e.,

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \ , \qquad (8)$$

and the general first order model in k dimensions becomes

$$y = \beta_o + \sum_{i=1}^{k} \beta_i x_i \ . \qquad (9)$$

To estimate the coefficients of a first order mathematical model in k dimensions a special class of experimental designs called "First Order Designs" has been created, (6, 7). In addition, as in the case of two dimensions, the two level factorial design also may be used to estimate the coefficients in a first order model in k dimensions. The 2^k factorial designs require $N = 2^k$ experimental points, whereas first order designs are available requiring only the minimum number of points, ie, $N = k + 1$. Of course as k becomes large the number of experimental points required in a 2^k factorial rapidly increases, and for this reason fractional factorial designs are frequently used which limit the number of points to 1/2 or 1/4 or a still smaller fraction of the total number of points originally required. The fraction permitted depends of course on the number of controlled variables involved.

In $k = 3$ dimensions the design points for a full two level factorial design, and a 1/2 replicate (1/2 fraction) of the two level factorial are as follows.

x_1	x_2	x_3
-1	-1	-1
1	-1	-1
-1	1	-1
1	1	-1
-1	-1	1
1	-1	1
-1	1	1
1	1	1

x_1	x_2	x_3
-1	-1	-1
1	1	-1
1	-1	1
-1	1	1

A 1/2 replicate of the 2^3 Factorial is identical to a Three Dimensional 1st Order Design

If these points are plotted in a coordinate system with axes x_1, x_2 and x_3 those of the full factorial design will form the vertices of a cube, while those of the 1/2 replicate will form the vertices of a tetrahedron. The first order design, in three dimensions is identical to the 1/2 replicate of the 2^3 factorial.

Two level factorial, and first order designs, can be constructed regardless of the number of dimensions involved (10). They become in higher dimensionality the vertices of a hyper-cube (or a particular subset of a hyper-cube if a fractional factorial is used), and the vertices of a hyper-tetrahedron respectively. On those occasions where the number of dimensions is one of the arithmetic series 3, 7, 11, ... a first order design will be found to coincide identically with some fraction of a two level factorial. For dimensions of a number other than these, the vertices of a tetrahedron cannot everywhere take on the value of plus or minus unity. For example, the vertices of a tetrahedron in four dimensions, i.e., the levels of the design variables in a first order experimental design in four dimensions are

Run No.	x_1	x_2	x_3	x_4
1	-1.581	-0.913	-0.645	-0.500
2	1.581	-0.913	-0.645	-0.500
3	0	1.826	-0.645	-0.500
4	0	0	1.935	-0.500
5	0	0	0	2.000

Applications of 1st Order Designs:

Estimating a Planar Response.

The theoritical physicist attempts to portray nature with the most elemental mathematical form possible. The first order mathematical model illustrated by the general equation

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_k x_k$$

is certainly the simplest of these forms. It states that the effect of, say, variable x_2 upon the response y is additive and quite independent of the roles of $x_1, x_3, \ldots, x_k$. We note that the familiar formulas from physics

$$E = IR \; ; \quad P = \frac{MRT}{V} \; ; \quad e = mc^2$$

when written in logarithmic form yield a first order model.

There are of course many experimental situations where a first order mathematical model, a straight line where there is one controlled variable, a plane where there are two controlled variables, and a hyperplane for more than two controlled variables, provides a meaningful representation of a response function. In these situations the coefficients in the first order model are best estimated using data obtained from the settings of the controlled variables determined by the coordinates of a first order, 2^k factorial or fractional factorial design. An illustration of the estimation of the coefficients in a first order model using a 2^2 factorial design was given above.

Estimating a Path of Steepest Ascent

Frequently the question is asked, "What combination of levels of the controlled variables will give the highest response?" In attempting to answer this question several alternative experimental approaches are possible. The experimenter may randomly select different settings of the controlled variables, try them in his laboratory or pilot plant, and with luck gravitate to the maximum point. Or he may run a sequence of experiments over a grid covering the entire region of interest and thus literally map the response. Both these approaches can quickly require a great many experimental runs and are avoided.

A favorite attack is the method of one factor at a time. This method requires that the experimenter hold all the controlled variables save one at some constant level, and then vary the remaining single variable until a maximum response is observed. Then holding this variable at its optimum value, a second variable is varied, and so on. The method is illustrated in Figures 1 and 2, for the case of $k = 2$ controlled variables.

Suppose a response y (% of theoritical yield) is a function of time (measured along the x_1 axis), and temperature (measured along the x_2 axis). Suppose further that the response, when viewed geometrically, has the appearance of a mound with a single maximum point. This response is illustrated by means of the contour diagram in Figure 1.

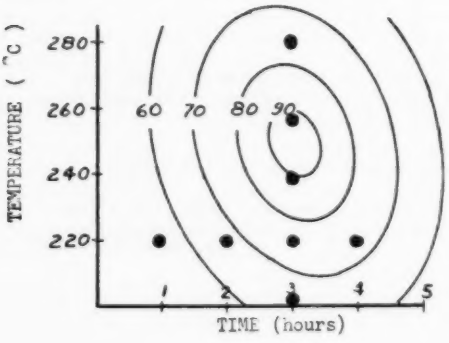


Figure 1

Contours of Equal Response for y % of Theoretical Yield

Illustration of Method of One Factor at a Time

Using the method of one factor at a time, the experimenter might hold the temperature constant at 220° and vary the time in one hour increments. The resultant experimental trials are shown by the horizontal line of heavy dots in Figure 1. Deciding that three hours was the best time, he would then hold the time constant at this value and vary the temperature in, say, increments of 20°. This gives the series of experiments illustrated by the vertical line of dots. Thus the procedure leads the experimenter to the point of maximum response.

However, imagine that instead of a mound, the response were only slightly more complicated and had the appearance of a rising ridge as shown in Figure 2.

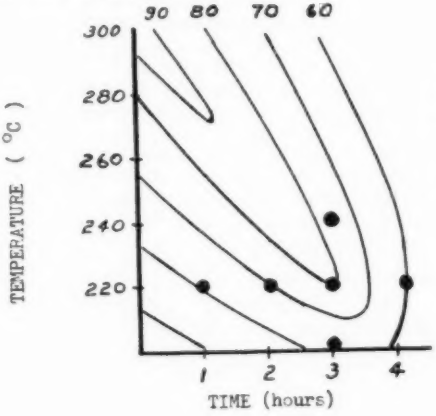


Figure 2

Contours of equal Response for y = % of Theoritical Yield

Illustration of Method of One Factor at a Time

The identical procedure illustrated by the dots in Figure 2 leaves the experimenter with the conviction that the setting of three hours and 220° is optimum, for steps higher or lower in time or temperature from this point will produce a decrease in the response. Obviously higher yields are possible. In this instance the experimenter is stuck on a ridge and can only discover the higher yields by varying time and temperature simultaneously.

A method which guarantees that the experimenter will tend towards the maximum point regardless of the form of the response surface (save that it is continuous) is the method of steepest ascents (3, 8, 9). This technique makes use of the first order mathematical model and either the two level factorial design or the first order experimental design. An important concept behind the idea of predicting a path of steepest ascent is simply that a plane does a good job approximating a curved surface within a limited area. This is analogous to the old argument that straight lines do a good job of approximating curved lines over small distances. The plan then is to predict the best fitting plane in some small sub-space of the experimental region. Then noting the tilt of the fitted plane, a path of steepest ascent can be predicted. Experiments are then performed along this path until a decline in response is noted. Additional observations taken in and around this point can confirm whether a

maximum has been reached, whether a new path of steepest ascent should be predicted, or whether the response surface should be mapped in this important region.

For example, imagine that a two level factorial design had been run as illustrated by the small circles in Figure 3

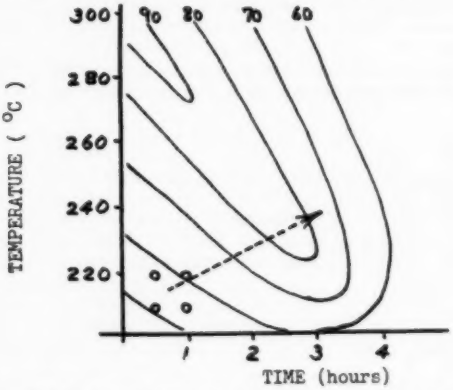


Figure 3

Contours of Equal Response for y = % of Theoritical Yield

Illustration of Path of Steepest Ascent

The following table of results would be observed:

Controlled Variable Levels		Experimental Design Levels		Response
Time	Temp.	x_1	x_2	y
0.5 hr	210°	-1	-1	51%
1.0	210	1	-1	57
0.5	220	-1	1	55
1.0	220	1	1	61

Fitting the first order model given in equation (5) one obtains for the best fitting plane in this region

$$\hat{y} = 56 + 3x_1 + 2x_2$$

The path of steepest ascent is now determined by the coefficients of x_1 and x_2. In this example we are advised that for every three units x_1 is changed, x_2 should be simultaneously changed two units. The changes requested are proportional to the size and signs of the coefficients in the first order model. The units that are considered here are the units of the design variables, not the levels of the controlled variables. The predicted path of steepest ascent is plotted as shown. Experiments along this path lead to the crest of the ridge where a second series of experiments would direct the experimenter up the ridge. Should the response be a simple mound as in Figure 1, the very first predicted path should lead the experimenter very close to the maximum point.

Screening for Important Variables

The first step in many experimental, development or production

problems is to find those few controlled variables having the most profound effect upon a response given that there are 10 or 20 or perhaps as many as 50 controlled variables. One method for attacking this problem has been suggested by Cuthbert Daniel who recommends that a highly fractionated 2^k factorial design be used to provide the information necessary to determine the most important variables. In essence the information obtained from the fractional factorial design is used to estimate the coefficients in the first order model

$$y = \beta_o + \sum_{i=1}^{k} \beta_i x_i$$

where k is a large number. Those controlled variables whose coefficients are found to be significantly different from zero are selected as the most important variables. The great concomitant value to the use of fractional 2^k factorials comes from the frequent repetition of the high and low levels of each controlled variable balanced across the many other controlled variables. This replication aspect of the designs greatly increases the ability of an experimenter to detect small changes in a response as a function of changes in a controlled variable. Of course the two level factorial design can also be used to contrast the effect upon a response of the presence or absence of some qualitative effect (such as the presence or absence of some bath treatment, chemical reagent or technique of handling) as well as the high versus the low level of some continuous controlled variable such as time.

The application of the 2^k factorial and first order designs to the problem of screening for leading controlled variables requires a careful choice of the size of the change to be made in the level of each variable. There are also many different ways in which the 2^k factorial design may be fractionated and a choice of the proper fraction requires at least a sense of the simultaneous roles of some of the variables. These designs have been expanded to include studies of the effects of more than two levels of different controlled variables generating the mixed factorial and fractional mixed factorial designs. Very recently F. E. Satterthwaite has suggested designs for screening for important variables in which the number of experiments is actually less than the number of variables studied. These designs, as yet unpublished, are useful whenever k, the number of controlled variables, is reasonably large.

Evidence of the Failure of a 1st Order Model

If a response surface is thought to be curved, then a planar representation is obviously no longer adequate. Fortunately, most of the first order designs described above can be made to give measures of the non-planarity of the response function. One such measure is provided by the interaction effects which can be estimated from the data provided by the 2^k factorial designs. For example, for $k = 2$ controlled variables, the two level factorial design provides enough information for estimating all the coefficients in the mathematical model

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_2 .$$

In this model a phenomenon called the "interaction" is given by β_{12}, the coefficient of the product of x_1 and x_2. The variable x_1x_2 is a second order term. If the coefficient β_{12} is significant it is testimony that a simple first order model is inadequate as a portrayer of the response.

Another measure of non planarity is provided by points run at the center of a design array. It is easy to visualize that if a response were planar then the value of the response at the center of an array of points such as those provided by the first order and 2^k factorial designs would equal the average of the response at the peripheral points. If the value at the center is significantly different from the average of the peripheral points we have in fact shown that the second order coefficients β_{11} and β_{22} together are significant. These two coefficients in addition to β_{12} are required to give a full second order model. This model is given below in equation (10).

Second Order Experimental Designs

Once the important controlled variables have been discovered, or once a region of maximum yields has been located, experiments are often required to describe the response as a function of the controlled variables over quite a wide range of these variables. This last requirement is met if the experimenter can actually construct the contour lines describing the form of the response surface. For example, there is a wealth of practical information made available by the contour diagrams shown in Figures 1 and 2.

On other occasions an experimenter or development worker may be asked to find a region which is optimum, not with respect to a single response, but with respect to two or more responses considered simultaneously. One interesting means for finding points or regions that are optimum with respect to several responses is to superimpose the contour diagrams of the responses. For example, imagine the response illustrated by the contours in Figure 1 indicate the yield of product A, and the response illustrated in Figure 2 indicate the yield of some simultaneously produced product B. By superimposing these two contour diagrams, as shown in Figure 4, one can determine the settings of time and temperature which will simultaneously give, say, a yield of 90 for A and a yield of 80 for B.

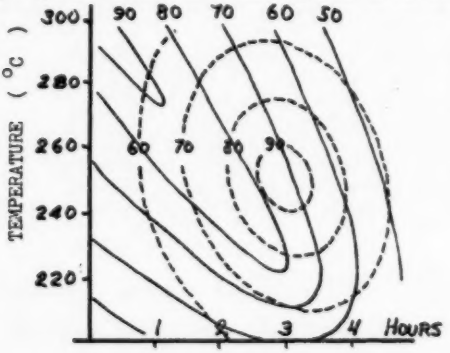


Figure 4

----- Contours for Product A

——— Contours for Product B

To estimate a non-planar surface a second order model can often be profitably used. The second order model in two dimensions is

$$\hat{y} = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 \qquad (10)$$

This is a very versatile mathematical model. Imagine that the coefficients in the model have been estimated. Next, set $\hat{y}$ equal to some constant, say $\hat{y} = 80$. The resultant equation will be the equation of a circle, an ellipse, a hyperbola, a parabola, or even a straight line. The actual geometric shape depends, of course, on the signs and magnitudes of the various coefficients. The important fact to remember is that everywhere on the line, regardless of its particular form, the predicted response $\hat{y}$ equals eighty. We have therefore predicted the contour line for $y = 80$.

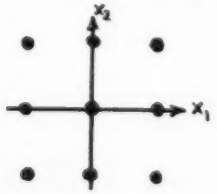
Thus, this mathematical model can be used to estimate the contour lines of many response surfaces (3,9). For example, imagine the 'unknown' response surface given in Figure 1: a simple mound. Imagine further that the response has been recorded at enough settings of time and temperature, x_1 and x_2 , so as to permit the estimation of all the coefficients in the second order model given in equation (10). Let us also assume that the error in measuring the response y is small. Once the coefficients of the second order model have been estimated, by setting $\hat{y} = 90, 80, 70$, etc. We would undoubtedly generate three concentric ellipses, the ellipse for $\hat{y} = 90$ being innermost, the ellipse for $\hat{y} = 70$ being outermost. These ellipses become in fact the predicted contour lines. Viewing such a set of contours, the form and nature of the response surface should be immediately apparent to the experimenter. In this example we would conclude that the response surface was a mound.

Second Order Experiment Designs

Estimating the six coefficients in the second order model given in equation (10) can become very awkward if care is not taken beforehand in selecting the levels of the controlled variables. One experimental design (not a rotatable design) that can be used to reduce this labor of computation is the three level factorial design. This design requires that each of the controlled variables be held at a high (-1) , middle (0) , and low (-1) level, and that all combinations of levels and variables be run. In general, the number of experiments required is $N = 3^k$, where k equals the number of controlled variables. Thus, the co-ordinates of a two dimensional, three factor factorial design are:

Experimental Design Levels

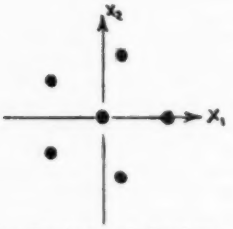
	x_1	x_2
Run no. 1	-1	-1
2	0	-1
3	1	-1
4	-1	0
5	0	0
6	1	0
7	-1	1
8	0	1
9	1	1



Plot of the Three Level Factorial Design

However, although this array of points will greatly simplify the calculations required for estimating the coefficients in the model, it provides an unfortunate balance in the variances of the estimates of the linear, interaction, and quadratic coefficients. As a matter of fact, the variances of the estimated coefficients will literally change as one moves about in the space of x_1 and x_2, even though one should move in a perfect circle about the center of the design.

An optimum class of experimental designs called 'Rotatable Designs' (10, 11, 14, 15) has recently been developed which not only possess the quality of easy calculations, but also provide that the variances of the estimated coefficients remain constant as one moves in a circle about the center of the design. This can be shown to be a very desirable property for any experimental design. Furthermore, the configuration of points in the space of x_1 and x_2 are easily remembered, for they form the vertices of the regular figures, starting with the pentagon. Thus the simplest second order rotatable design is illustrated below



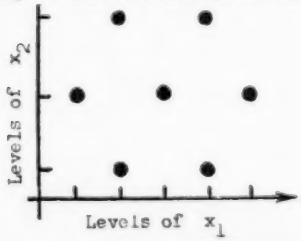
The Pentagonal Design

Design Co-ordinates

x_1	x_2
0.000	0.000
1.000	0.000
0.309	0.951
-0.809	0.588
-0.809	-0.588
0.309	-0.951

It should be noted that an additional required point is one (or more) at the center of the design array. Replication of this single point will not only provide a valid estimate of the experimental error, but is also valuable in building up the predictive power of the resultant fitted model in the interior of the design.

The hexagon, septagon, octagon, etc., all with one or more center points, provide second order rotatable designs. The choice of one rotatable design over another is usually determined by the number of trials the experimenter wishes to run, and by the number of levels he must maintain for each variable. For instance, a hexagon design requires that x_1 be controlled at Five different levels, but x_2 only at three different levels, i.e.,



HEXAGONAL DESIGN

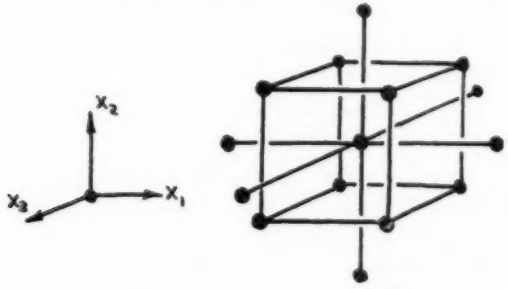
x_1	x_2
0.000	0.000
1.000	0.000
0.500	0.833
-0.500	0.833
-1.000	0.000
-0.500	-0.833
0.500	-0.833

k - Dimensional Second Order Designs

It is of course possible to extend the second order mathematical model to higher dimensions, i.e., to consider a curved response as a function of three or more controlled variables. In these instances the experimenter will predict contour surfaces instead of contour lines, and although the interpretation, and visualization, of second order responses in three or more dimensions is not easy, it has been successfully accomplished in several instances (8, 9, 12, 13). The second order model in three dimensions is

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \quad (11)$$

Three rotatable k = 3 dimensions, second order experimental designs exist: the icosahedron design which is formed by the 12 points at the vertices of an icosahedron plus one or more points at the center, the dodecahedron design with 20 points plus one or more at the center, and finally the cube plus octahedron design -- better known as the 'central composite design' (7) -- formed from the 8 points of a cube, the 6 points of the octahedron, and one or more points at the center of the array. This latter design is illustrated below.



Three Dimensional Central Composite Design

To form a rotatable design from the central composite design, the radius arm of the octahedron must equal 1.68. The co-ordinates of the vertices of the cube all equal plus or minus one. Rotatable designs, in the form of the central composite design, are available in all dimensions.

Conclusion

It has only been possible to paint with a very broad brush the concepts of steepest ascent and surface fitting, and to briefly describe the experimental designs associated with these methods. For a more detailed description of steepest ascent and surface fitting one should read reference (7). Another excellent description, coupled with careful explanations of the numerical details appears in (3). The portion of this book describing these topics is written by Dr. G. E. P. Box, the originator of these methods.

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BREAKING THROUGH INDUSTRIAL PROBLEM BARRIERS

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There seems to be a lot of truth in the saying, "There Is Nothing New Under The Sun". The tremendous advances being made in practically all fields apparently are coming about as a result of putting together basically what we already know in a different way, or using such information in new places. Quality Control practices and related techniques can do for us much more than many of us may have realized or even imagined. Some of us have been breaking through industrial problem barriers, which seem to many industrialists as impenetrable as aeronautical engineers rather recently considered the sound barrier. It is time more of us approach barriers as something to be overcome rather than as "a given situation" with which we should set up a model so as to determine the optimum operation.

Consider these examples, all solved by the approach described in this paper:

Industry	The Problem	Suspected Cause	Actual Cause
Plating	A polishing operation following plating was occasionally exposing base metal.	Varying skill of the several polishers and differences among polishing wheel materials.	Position of heating coils in the plating tanks.
Casting	Porosity	Casting design, gating and venting of the mold, or operator skill.	Melt temperature being controlled at the wrong level and an uncontrolled mold temperature.
Paper	"Excessive" variation of several final properties.	Uncontrollable raw material variation - "Trees don't grow alike".	A constant digester cooking cycle resulting in large variation in freeness of blown digester loads.

Industry	The Problem	Suspected Cause	Actual Cause
Pneumatic	Too high a supply pressure needed for proper operation of assembly.	Misalignment of intersection of internal air passages and internal burrs.	Incorrect mechanical advantage in an indicating mechanism and insufficiently precise control over a diametral clearance.
Metal Slitting	Too low an average no. of pieces per rotary saw. The saws dulled or broke.	Saw and/or stock material, S.F.P.M. cutting rate, and type of coolant used.	Out of round of saw bores and undersize spindles resulting in eccentric running of cutting teeth.
Lapping	Occasional objectionable scratches a few millionths of an inch deep.	Particles (in air settling on work, coming out of the cast iron laps, or out of the material being lapped).	Condition of lapping compound solution just at the critical point in the entire lapping cycle.
Drilling	Gun drill breakage.	Amount of sulphur in cutting oil, chip breaking provisions, and material being drilled.	Belt driving work, while drill advanced, was not tight enough to avoid slight slippage.
Rubber	Unpredictable no. of failures of rubber bond to metal.	Chemical cleanliness of metal, seasonal humidity, and differences in batches of adhesive.	Platen temperature at molding of assembly was being changed slightly and occasionally to bring shear value of rubber within specs.
Aircraft Accessory	Requirement to reduce to 1/2 the fuel flow tolerance at all compressor discharge pressure test points.	Unavoidable accumulation of numerous important part tolerances (already as tight as can be produced).	Simple oversight in the setting procedure of each unit on the calibration rig and an incorrect nominal value specified for one important spring in the assembly.

Since many of the suspected causes were things that were not practical to change, these problems were creating other problems in the areas of scrap allowances, production control, price, delivery dates, personnel requirements, and so forth. In such typical industrial situations, Management, observing the failure of its technical personnel to find a ready solution, unfortunately considers the difficulty as inherent to the process. So the managers either accept the situation as inevitable or authorize a research program to find a completely different way of getting the desired product.

It is the purpose of this paper to bring out that a much more economical and time-saving approach can be used whenever a situation does not respond favorably to what seem to be the obvious corrections. The cases mentioned above had been a problem for one year, for the shortest, up to over 20 years. More than half of them had a serious effect on the plants' operations for more than 10 years.

Finding the actual cause (significant at least at the 95% level) and from that determining the successful corrective action took a time measured just in weeks (6 weeks was the longest).

This reasoning led to the approach used:

1. Every effect has one or more contributing causes.

2. These causes do not contribute equally to the effect.

3. In accordance with Pareto's principle, [1] a very large part of the total effect almost invariably comes from relatively few causes.

4. These few causes (often being only <u>one</u> cause) are not constant in their activity. [2]

5. A simple analysis of the variation of the total effect should give clear clues as to the nature or limited area of the important cause or two. [3]

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1 - Vilfredo Pareto, 1848-1923, Italian economist and sociologist.

2 - A basic SQC concept: There is variation in all activity.

3 - Using one or more of the following, as applied to the overall operation: Multi-Vari Chart (due to L. A. Seder) to get the relative size of within unit, unit to unit, and time to time variation; a set of simple 2-factor scatter diagrams to locate the element associated with maximum variation; parallel path experiment to isolate the culprit operation from among a series of operations; and Latin Squares for interchangeable components of assemblies.

6. One or two quite moderate-size[4] statistically analyzed experimental designs can then identify with 95% assurance, from the few suspected causes, which are contributing most to the effect.

7. Whenever more than one important causesare acting simultaneously (and their nature is different so the clues of step 5 are not clear) it is possible to separate estimates of the contribution of each by a statistically analyzed experimental design.

8. Whenever important causes interact, estimates of their separate effects as well as their significantly different joint effect can be determined by certain types of statistically analyzed experimental designs.

For convenient reference this sequence of 8 steps will be called the "concept of largest variation" in this paper.

This approach has a different starting point from the conventional problem solving procedure. It may well be the reason for the difference in the record of successful and more rapidly determined solutions. Conventionally a problem usually starts one theorizing as to possible causes. The prior data, if any, which are looked at have not been gathered in such a way to permit even a rough statistical analysis.

An experiment is then run changing one of the causes, which seems responsible. Under this arrangement there is no possibility of finding interactions. In fact their presence would only further confuse the conventional experimenter. Then the data are taken on test material, usually handled in systematic order from a source of such material. That procedure permits any differences among test samples to be confounded with the main effect being studied. Failing to randomize also becomes the practice in running the parts of the experiment, thus allowing any number of additional "environmental" causes of variation to be confounded with the main effect.

The more sophisticated approach of the statistician, who conducts a properly balanced and randomized experiment, usually also involves starting with the same possible causes (often specified by the person living in the shop with the problem). In contrast the concept of largest variation requires there be statistical evidence to justify including a suspected cause in the experiment. So it is no wonder that the statisticians' experiments so often show results, which are not significant; and that sometimes more effort is put into the experiment in the form of increased replication to attempt to bring out the significance of a factor (most likely one of the great majority, according to Pareto's principle, which has a minor effect).

For the foregoing examples here were the nature or limited area of largest variation found in step 5 of the 8 statements of reasoning:

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4 - Only few levels of factors and few replications are needed for large effects.

Plating - A preliminary run of parts unexpectedly showed no significant difference among polishers. Going to the 14 plating tanks with a Multi-Vari approach showed the within tank component to be the largest by far.

Casting - Again by Multi-Vari the largest component was clear: Time to time within a lot of castings, with the porosity reducing with increasing time.

Paper - Multi-Vari showed batch to batch prominence.

Pneumatic - An interchange of components of the assembly in accordance with a Latin Square design showed the maximum variation to be associated with just two parts.

Metal Slitting - Scatter diagrams showed saw to saw variation standing out.

Lapping - Scatter diagrams singled out lapping compound float batch to float batch.

Drilling - The Multi-Vari approach brought out the fact that the largest variation in drill life came from station to station among the four stations of the multiple head machine.

Rubber - Batch to batch variation in bond strength exceeded all other components on a Multi-Vari chart.

Aircraft Accessory - This Multi-Vari plotting revealed a combination of unit to unit variation and maintenance of relative position of a unit's fuel flow at all test points.

The successful application of the concept of largest variation requires confident cooperation from Management and line supervision in the plant. This favorable situation almost only exists when they really understand statements 6, 7, and 8 of the concept. Rath and Strong has accomplished this with clients through the device of an 18 hour course on analysis of variance. The following brief outline of the course may suggest a way the quality control man can communicate, using simple arithmetic as contrasted to "mathematics", to bring about this understanding in his plant.

1. One reading at each level of just one factor provides little information about what can be expected in the future at those levels.

2. With repeat readings, one has to evaluate the probability that the lack of repeatability at each level can cause the observed differences among averages for each level; and one has to force by randomization each effect, coming from any other source than the cause being studied, to be distributed among all the individual results in a pure chance pattern.

3. The mean square among levels will be an estimate of the experimental error (variance among individuals) plus the variation due to change in levels (variance among averages).

4. Student participation in the mechanics of filling out an analysis of variance table from an example of test readings for a single factor experiment. This sort of participation is required at almost every step of the course.

5. Background for this table is given by intuitive numerical derivation rather than rigid mathematical proof. Covered are the normal distribution, derivation of σ and of σ^2, the necessity of working from a sample from the population, what degrees of freedom mean and why they are used, and the expression for mean square along with the names of its terms as used in the table.

6. A numerical demonstration of sample readings shows (a) total variation in the array can be split into two arrays, one showing only that among levels and the other showing only that within levels, and (b) the example works out that the sum of squares of each part added gives the total sum of squares.

7. In numerically working out the background for the expressions being estimated by the mean squares, the important relation between mean square of means and mean square of individuals is derived.

8. Coding data by subtracting the average of all readings from each reading accomplishes the same thing as the term "correction for the mean".

9. The multi-factor experiment gives more information per reading and permits the detection of interactions.

10. The importance of understanding the difference between statistical inference and such as engineering inference.

12. Analysis of the two-factor experiment starts with a numerical demonstration of one factor nested within the main effect. Considerable simplification of notation, over that used in contemporary texts, has to be used from this point on to retain the understanding of the participants.

13. Explanation of rules for pooling components of variation.

14. The changes in the F ratio expression brought about by finite and infinite populations to which inferences from the experiment are to be extended. How to get degrees of freedom for the special expression sometimes required for the denominator of the F ratio.

15. Two crossed classifications.

16. Three crossed classifications.

17. Number of groups of effects as the number of factors increases. The need for using the concept of largest variation.

18. A completely nested three factor classification.

19. Both types of classification in one experiment, nested and crossed.

20. Rules for getting the expression for the sum of squares for main effect, interaction, nested, interaction nested, and error; for getting degrees of freedom of each; and for the expressions being estimated by each mean square.

21. Analysis of variance of attribute data.

To break through industrial problem barriers the objective approach of letting the operation tell on itself is quite a help. Let us stop employing, subconsciously or otherwise, the subjective one of opinions based on "long years of experience with the job".

PRACTICAL APPLICATIONS OF S.Q.C. TO THE BREWING PROCESS

Philip E. Dakin and Larry K. Neuman
Miller Brewing Company

It is readily recognized that the field of brewing is becoming more and more competitive, more and more scientific, and more and more big business. It should equally be recognized that, to meet this challenge of competition, this precision of science, and the enormities of big business, we have to keep pace with modern developments in statistics.

Based upon our experience over the past three years, we have come to the conclusion that, in a good many instances in a brewery, the application of statistics to quality control has a very close corollary to other industries. Consider, for example, receiving inspection. Sound sampling plans are necessary for shell casings or for beer cans, for nuts and bolts or for bottle caps. The characteristics being tested may differ, but the validity of test results and calculations therefrom depend directly on the validity of the sample. Consider, also, the raw materials used in brewing. Sampling from carload lots of malt differs very little from the batch lot sampling necessary in the chemical industry.

Take a sound sample and quarter it down to give you sixteen smaller samples, each sufficiently large enough to allow complete laboratory analysis of all tests desired. Upon completion of the analysis on all sixteen samples you will find a normal variation of answers around a mean or average. If there is not a variation, then one can say that probably the method of analysis is not sensitive enough to pick up the variation present.

It is not at all very difficult, now, to apply some simple statistics and calculate standard deviation on each set of data. This standard deviation, designated σ (sigma), is an accurate estimate of the spread in results you may expect when you analyze a sample of malt. This standard deviation says in effect, "Based upon our present method of analysis and the techniques employed by our laboratory staff, we can expect laboratory results to fall within these limits." Now the brewer has one of the basic tools necessary for a sound program of checking incoming cars from a number of malt suppliers who are shipping against specifications. Likewise, the maltster who has applied the above technique has a sounder basis for shipping against specifications. Figure 0 is a typical form that can be used for an evaluation of a supplier's malt.

We have now applied some simple mathematical calculations to the laboratory analysis of one of the basic raw materials of beer. This raw material ends up in the brewhouse, so let us now consider applying statistics to the brewhouse process.

Major brewers today, depending upon their annual production and the size of their kettles, may make anywhere from four to forty or more brews per day. These brews are made under standard conditions which result in a normal process with its inherent variation. Ballings or hydrometer readings to determine percent solids in each brew are as much a standard procedure as the brewing formula is itself. These ballings are really a measure of the process variation. Why not set up an $\bar{X}$ and R chart to study this variation so that we know what the process is capable of doing and also that we know when we are in trouble or may expect trouble. Just

MONTH OF MARCH, 1956

SUPPLIER: "A"
CARS SHIPPED FOR MONTH: 15
CUMULATIVE SHIPMENT FOR YEAR: 35

CLASSIFICATION CODE:
97.50% - 100.00% - Excellent
95.00% - 97.49% - Very Good
92.50% - 94.99% - Good
90.00% - 92.49% - Fair
Up to - 89.99% - Poor

			OVER-GROWN	% ON 7/64" SCREEN	% ON 5/64" SCREEN	THRU 5/64" SCREEN	% S/T	D.P.	ALPHA AMYLASE	COLOR OF WORT	COLD WATER EXTRACT	DIFF. FINE-COARSE	AVERAGE % IN SPEC.
INDIVIDUAL SUPPLIER	MONTH	AVERAGE	----	----	----	----	----	----	----	----	----	----	
		STD.DEV.	1.44	1.27	0.91	0.31	0.65	2.00	0.79	0.08	0.19	0.23	
		ESTIMATED:											
		% IN SPEC.	99.86	38.67	100.00	99.98	61.03	100.00	100.00	90.75	95.91	100.00	88.62
		% ABOVE SPEC.	0.14	----	----	0.02	----	----	----	8.38	4.09	----	
		% BELOW SPEC.	----	61.33	----	----	38.97	----	----	0.87	----	----	
		CLASSIFICATION	Exc.	Poor	Exc.	Exc.	Poor	Exc.	Exc.	Fair	Very Good	Exc.	
	CUMULATIVE	AVERAGE	----	----	----	----	----	----	----	----	----	----	
		STD.DEV.	1.48	1.56	0.97	0.37	0.70	2.08	0.84	0.08	0.20	0.24	
		ESTIMATED:											
		% IN SPEC.	99.82	77.51	100.00	99.84	70.13	99.99	100.00	93.72	99.06	100.00	94.01
		% ABOVE SPEC.	0.18	----	----	0.16	----	0.01	----	4.01	0.94	----	
		% BELOW SPEC.	----	22.49	----	----	29.87	----	----	2.27	----	----	
		CLASSIFICATION	Exc.	Poor	Exc.	Exc.	Poor	Exc.	Exc.	Good	Exc.	Exc.	
ALL SUPPLIERS	MONTH	AVERAGE	----	----	----	----	----	----	----	----	----	----	
		STD.DEV.	1.39	2.05	2.41	0.37	1.07	2.17	2.40	0.06	0.33	0.31	
		ESTIMATED:											
		% IN SPEC.	99.84	86.53	98.61	99.41	83.84	100.00	77.64	96.56	89.80	99.87	93.21
		% ABOVE SPEC.	0.16	0.36	1.39	0.59	7.78	----	----	3.36	10.20	0.08	
		% BELOW SPEC.	----	13.11	----	----	8.38	----	22.36	0.08	----	0.05	
		CLASSIFICATION	Exc.	Poor	Exc.	Exc.	Poor	Exc.	Poor	Very Good	Poor	Exc.	
	CUMULATIVE	AVERAGE	----	----	----	----	----	----	----	----	----	----	
		STD.DEV.	1.45	2.11	2.57	0.42	1.09	2.20	2.57	0.06	0.30	0.30	
		ESTIMATED:											
		% IN SPEC.	99.77	91.07	98.28	98.89	82.92	99.97	82.76	98.26	92.41	99.91	94.42
		% ABOVE SPEC.	0.23	0.83	1.72	1.11	7.25	0.02	----	1.51	7.59	0.06	
		% BELOW SPEC.	----	8.10	----	----	9.83	0.01	17.24	0.23	----	0.03	
		CLASSIFICATION	Exc.	Fair	Exc.	Exc.	Poor	Exc.	Poor	Exc.	Fair	Exc.	

FIG. 0.

for kicks, let's include on this chart the ballings we get on the same brews after cooling and the ballings we get on these brews after fermentation. Maybe we can tie a few things together that weren't quite so evident before. Such a chart might look like Figure 1.

This chart is not the conventional type of $\bar{X}$ and R chart inasmuch as the range is shown by a vertical line running from the highest value to the lowest in the sample of size n. The control limits on these vertical bars (the outer two dotted lines) are actually the calculated control limits for individuals (single brews).

The sample size or each point on the chart can be chosen anywhere between two and twenty-four brews. However, it would be easier to handle if the sample were between perhaps four and nine brews. Such a chart shows you your process variation in terms of the average and range of n samples. It also can tell you when to expect trouble, and certainly tells you when your process or an individual brew is out of control. Also, suppose you are making eighteen brews per day over three shifts, or six per shift. If you use a sample of six and plot the average of six brews from each shift, you now have a convenient tool for watching shift differences. If every fourth point is consistently low, you might seriously suspect that one shift isn't doing as good a job as the others. Also, if every fourth bar is consistently longer, it indicates more variation on one shift than is present on the others.

Control charts are perhaps the easiest, most convenient, and most practical way of introducing statistical quality control into any company. A chart like the following, Figure 2, if properly presented, could gain immediate acceptance of a S.Q.C. program by top management.

This particular chart describes the alcoholic content, by weight, of 3.85 beer. It is a conventional $\bar{X}$ and R chart based upon a sample size of five. Control limits for both average and range are calculated on the basis of factors conveniently worked out by someone else. The chart itself is divided into five sections, allowing working space for the five possible weeks or portions of weeks within any one month. A very interesting and functional part of the chart is the small monthly averages chart which appears down in the lower right hand corner.

With slight changes, charts like Figure 2 can be used to report and control stability of beer, condition of yeast, air content, filler operation, CO_2 content, and foam properties, to name a few.

A small number of charts like this scanned at the end of each month, gives our top management a complete picture of the chemical and physical characteristics of our beer. A pictorial view of process operations can be had in a glance. No more tedious daily checking of long, typewritten forms to try to get the story of these all-important properties; no more searching and trying to remember what was on that tabulated report handed in yesterday, or last week, or last month. These charts, because they are time-saving devices, sold our top management. And more important, they graphically, emphatically, and even dramatically tell the story of process variation, both inherent and otherwise. Almost inevitably it follows, "Let's do something about that 'otherwise' variation." There is usually an assignable cause.

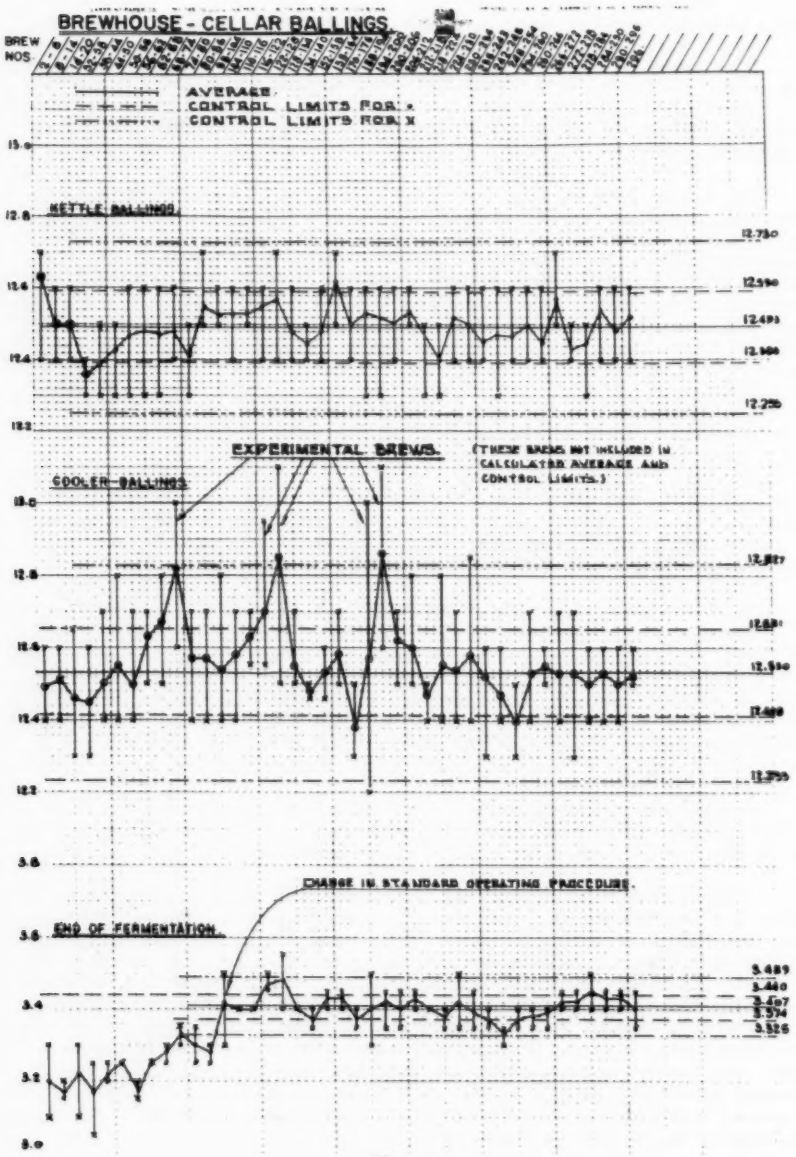
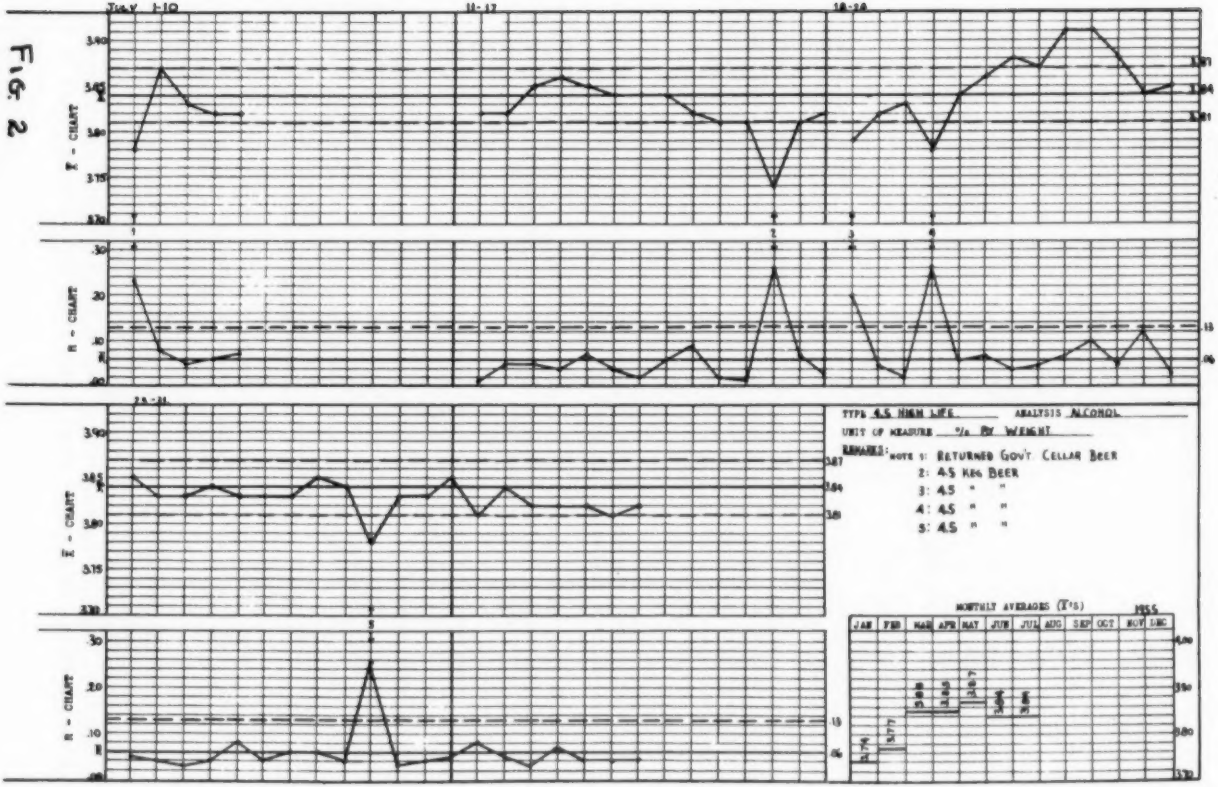

BREWHOUSE - CELLAR BALLINGS
BREW NOS.
AVERAGE
CONTROL LIMITS FOR x
CONTROL LIMITS FOR X
KETTLE BALLINGS
12.750
12.590
12.493
12.430
12.235
EXPERIMENTAL BREWS.
(THESE BREWS NOT INCLUDED IN CALCULATED AVERAGE AND CONTROL LIMITS.)
COOLER BALLINGS
12.827
12.681
12.590
12.499
12.355
CHANGE IN STANDARD OPERATING PROCEDURE
END OF FERMENTATION
3.489
3.440
3.407
3.374
3.326

FIG. 1.

Fig. 2


JULY 1-10
11-17
18-20
X - CHART
R - CHART
21-31
TYPE 4.5 HIGH LIFE
ANALYSIS ALCOHOL
UNIT OF MEASURE % BY WEIGHT
REMARKS: NOTE 1: RETURNED GOVT CELLAR BEER
2: 4.5 HIGH BEER
3: 4.5 " "
4: 4.5 " "
5: 4.5 " "
MONTHLY AVERAGES (X's)
1955
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

For further practical applications of statistics to brewing, let us for a moment consider the effect of filtration upon stability of beer. This, of course, presupposes a reliable method of checking stability. Assuming that such a method is available, let's investigate the use of plate filters (pulp or paper) as they may affect this all-important characteristic of beer. The investigation may be concerned with several different types of plate filters, or it may have to do with different sections of one filter. Nevertheless, we have one variable, namely, filters, that we wish to check. How can we best do this? One method might be to set up the two filters, hold every other possible variable constant, and run the same beer through both systems, taking samples after a predetermined time to check for stability. This procedure could be repeated several times and the results averaged. Undoubtedly, an investigation following this approach will arrive at some answers which may or may not be correct. In fact, under such an approach, the investigator may not consider the small problem of experimental error; he may not even have any idea of just how great his experimental error is.

Even so, assume that a decision is made that one filtration system does a better job than the other. Now it remains to determine how long the filter can be run effectively and, after that, at what flow rate can it best be operated. Assuredly, these questions can be answered, perhaps correctly. However, granted that the above approach may not do justice to a good unstatistically-minded researcher, it remains that very seldom, if ever, are all the possibilities considered. If they are soundly considered, the amount of experimentation under such an approach becomes prodigious.

A statistical approach to the problem, which assures the experimenter of an accurate estimate of error, might be as follows.

"Let's see, we've got to determine how stability is affected by two different filtration systems. A simple one-factor design, such as the following, will answer that question:

FILTER 1		FILTER 2	
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

"This design means that we'll have to make eight different runs on each filter, taking off samples at a certain specified point in the runs to check the different aspects of stability. At what point do we take the samples? Why not consider right away the variable of length of run and its effect on stability. Then our design will look like this:

	FILTER 1		FILTER 2	
LENGTH OF RUN 1	_____	_____	_____	_____
	_____	_____	_____	_____
LENGTH OF RUN 2	_____	_____	_____	_____
	_____	_____	_____	_____

"Still only sixteen experiments, but we get three times as much information from this design as compared to the first one. We check the over-all performance of two different systems; we break them down into lengths of runs, and, if the possibility exists that a particular filter running for a particular length of time does the best possible job, we'll also find that out.

"Now, one other important aspect in operating a filter is the flow rate. Once we've decided on the flow rate, we can run the design. How do we decide? You've guessed it! Let the design tell us. Now it looks like this:

	FILTER 1		FILTER 2	
	Flow Rate 1	Flow Rate 2	Flow Rate 1	Flow Rate 2
LENGTH OF RUN 1	_____	_____	_____	_____
	_____	_____	_____	_____
LENGTH OF RUN 2	_____	_____	_____	_____
	_____	_____	_____	_____

"Still sixteen experiments, now seven times more information than the first design would give. We get a comparison of the three main factors - filters, lengths of runs, and flow rates. We also get a check on all four possible combinations of the three main factors - filters and lengths of runs, filters and flow rates, lengths of runs and flow rates, and lastly, filters, lengths of runs and flow rates combined."

All of these comparisons, as well as the estimate of experimental error, are made on the basis of an analysis of variance on the measured experimental results.

Incidentally, it should be evident to some at this point that, when we ran those sixteen determinations on malt to get an estimate of variation in laboratory results, we could have tossed in the variable of different mashing machines, of different operators, and possibly the variable of different probe samples. Then, from our original sixteen analy-

ses, we could have determined whether or not any one, or all, or combinations of some of these factors introduced a significant variation or difference in laboratory results.

In all product experimentation in a brewery, whether it be on a pilot plant scale or production level, one all-important aspect that has to be considered is effect on taste. Maybe we have very good reason to believe there will be none. Maybe one small change will affect taste. At any rate, it remains to be determined, "Does the proposed change affect taste?"

One of the first groups to check for this possible taste difference is comprised of the master brewer and his associate brewmasters. However, most master brewers today insist upon the added assurance of a sound taste test program to verify their judgments. This taste test program generally makes use of individuals, other than the above-mentioned group, who have not had years of brewing experience or close association with the product. How, then, can the person responsible for a taste test program assure himself that the results he is reporting to the brewmaster are correct and sound? One of the best possible ways is to apply the laws of probability to the taste panel results. By applying these laws, the following question can be answered. "If two samples of beer are served to a panel of 20 people, what is the probability that 15 of the 20 will prefer one sample over the other merely by chance?" After all, if the panel of 20 simply looked at the two samples and indicated preference, you might expect most of the time that results would be 10 and 10. How often would these results turn out to be 15 and 5? By carrying out the expansion of the binomial for 20 taste testers, $(p + q)^{20}$, where the probability that by chance alone either sample 1 or sample 2 will be preferred equally or one half of the time, we find that a 15 and 5 result could occur by chance alone about once every twenty tests. If you get this 15 and 5 result on the first test, you might question seriously if the result were merely a chance one. You might accept, with a good degree of assurance, that the panel definitely preferred one beer over the other because, for some reason, the two beers did not taste alike.

The same type of calculations can be used to check the results of triangular taste tests where a panel is asked to pick the odd sample out of three samples tasted. Of course, the expansion of the binomial gets cumbersome and tedious as panel sizes increase. But as the panel size increases, results become more valid. Fortunately, it is quite easy to find complete tables, for panels up to 1000 people, where the results necessary to establish significance have already been calculated out.

With the establishment of a sound taste test program, we have for the most part touched upon the entire brewing process, from the raw materials used to the taste of the finished product. Certainly, we have not exhausted all the possibilities where S.Q.C. can be applied. The following flow sheet (Figure 3) of a typical brewing operation points out the places where statistical quality control techniques have been used successfully. These techniques include frequency distributions, a variety of control charts, tests of significance, random sampling plans for incoming materials, analysis of variance, and design of experiments.

We feel it important to re-emphasize again the point previously made regarding the ease of presentation of data to management by means of control charts. Not only are the charts a natural for introducing and continually acquainting key production men with S.Q.C., but these men, the Master Brewer, Associate Brewmasters, and other top technical personnel, sitting in weekly sessions, can, in a short period of time, peruse the whole "picture" of product characteristics. Such weekly sessions, coupled with monthly reviews, begin to point out possible sources of trouble. Quarterly reviews may indicate forthcoming inherent changes. Yearly reviews begin to show effect of materials, and even seasonal changes. Certainly, this is a practical application.

The above approach to the application of S.Q.C. in brewing may seem to be very general and, in some places, even trivial. However, it was not the purpose of this paper to discuss in detail specific applications, but rather to point out the numerous possibilities that exist where S.Q.C. can be used to excellent advantage. Actually, as we all know, much hard work is necessary in installing and growing up with a sound program of statistical quality control. It is not abnormal to meet resistance at every turn when you begin to get your feet wet. Normally, top management is not easily sold on the idea and your efforts, in many instances, may end in temporary discouragement. In our own particular case, we had right from the very beginning the complete backing and encouragement of our Vice President and Master Brewer, Mr. E. W. Huber. Consequently, our efforts were, from the start, rewarding. Conceivably, where much initial resistance must be overcome, the reward should be even greater.

Nothing sums up our feelings better on S.Q.C. than the following quotation taken in part from Dr. D. B. DeLury's final lecture at the close of an eight-day course on S.Q.C. Dr. DeLury was speaking about designed experiments, but what he said holds true, we think, for S.Q.C. in general.

> "99% of a planned experiment is based on previous knowledge. The 1% attributable to statistics can, however, determine the success or failure of the whole thing. Statistics give the little set rules, specific rules, with which we can analyze our information. Statistics is not a substitute for judgment, but only a tidy way of arriving at an accurate and precisely focused judgment."

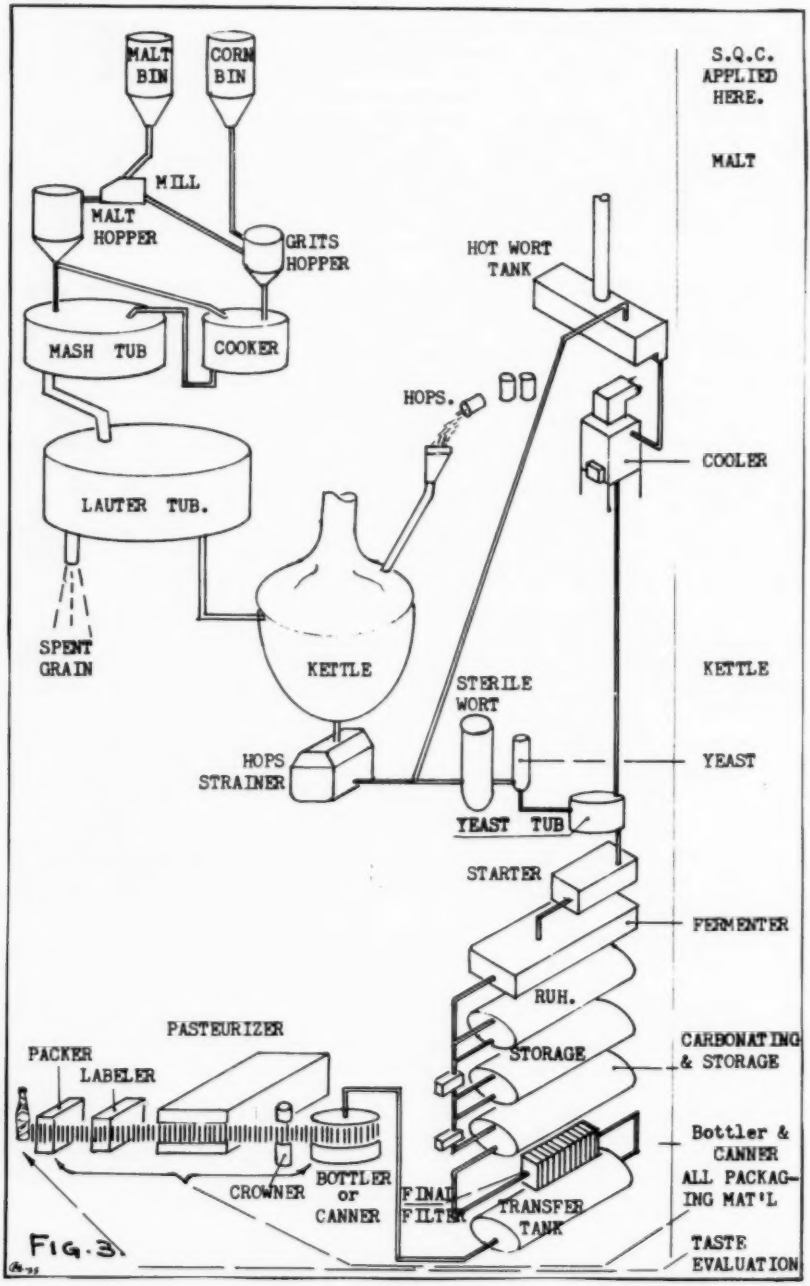

MALT BIN
CORN BIN
MILL
MALT HOPPER
GRITS HOPPER
MASH TUB
COOKER
LAUTER TUB.
SPENT GRAIN
KETTLE
HOPS.
HOPS STRAINER
HOT WORT TANK
COOLER
STERILE WORT
YEAST
YEAST TUB
STARTER
FERMENTER
RUH.
STORAGE
PASTEURIZER
PACKER
LABELER
CROWNER
BOTTLER or CANNER
FINAL FILTER
TRANSFER TANK
S.Q.C. APPLIED HERE.
MALT
KETTLE
CARBONATING & STORAGE
Bottler & CANNER
ALL PACKAGING MAT'L
TASTE EVALUATION

FIG. 3.

QUALITY CONTROL IN A COARSE GOODS MILL

R. R. MacNeil
Cosmos Imperial Mills, Ltd.

In coarse goods mills, fine goods mills, or still-to-be-defined average mills, supervisors are over-worked. The tendency throughout industry is to establish the department head, whatever his job, as a manager: a manager responsible for implementing company personnel practices; maintaining smooth labour relations; reaching and remaining at high production levels; scheduling the flow of materials in, through, and from his department; keeping labour and supply costs at a minimum; ensuring maximum results from an incentive system of pay; recommending and advising on capital expenditures; extracting the correct amount of waste; maintaining machinery; and controlling quality.

The relative importance of these facets of supervision depends on many influences, and one of the most important governing factors is the type of goods produced. Quality control can receive only a small amount of attention, and the nature of the product of the coarse goods mill tends to place quality problems far down the list of priorities. Analyses confirm, however, that a proper system of quality control is an aid to the supervisor, and an early result of the installation of a recognized system is the proof that adherence to quality standards is essential if any mill is to maintain a competitive position costwise.

The adoption of a formal quality control program requires the advice of specialists if maximum benefit is to be derived--and consultants cost money. The reason for the company decision to make the required investment can have far-reaching effects on the success or failure of the system. In many cases, unfortunately, a senior executive reads the first few lines of an article in a trade magazine, and makes a snap decision to buy a package deal--which is then thrown at his front-line management with no previous discussion. Such forced feeding will inevitably reduce drastically the effectiveness of the program in any organization--and the reaction of the supervisor in the coarse goods mill is bound to be even more violent. His questions are only natural; he may well be tempted to ask: "Haven't we been selling these goods for years without this foolishness? Our product isn't going to be worn--it's covered with rubber, or painted, or just used on machinery to make something else; we don't have to worry about its grade like the fellows who make clothes." A lengthy program of supervisor education is particularly essential if fair answers are to be given, and such education should be carried down through the organization to every employee.

Provision of assistance in maintaining a high level of consistency in the products of each process of manufacture is a primary task of the Quality Control program. The basic concept is not control but <u>assistance</u>; acceptance of this aim will minimize the danger of poor line and staff relationships.

Without getting into semantics too deeply, should we not give some thought, as a Society, to our use of the word "control"? The existence of our independent nations on this continent results from an historic dislike of controls--is it any wonder that American and Canadian supervisors refuse to welcome a change which by its very name implies re-

striction on their activities?

The policy of "management by exception" is a solution to this very real problem, and has helped greatly to overcome such objections. The essence of the policy is that the supervisor is left free to concentrate on his other countless tasks, and only when conditions warrant his attention is he required to devote time to quality.

Raw Material Effects

A thought-provoking question is commonly asked; "We got along without it for years, why bother now?" Perhaps it is human nature to answer this by blaming the supplier, but few mill men who process natural textiles will deny that the quality of goods supplied them has worsened in recent years. In cotton textile manufacturing particularly, the most pressing reason for spotlighting and revising many phases of mill operations, especially in the early processes, goes back to the cotton farmer and gin operator. Raw material costs are relatively high in coarse goods manufacture; cotton which is mechanically picked, and grown and ginned to government specifications rather than actual primary textile requirements, is presenting tougher problems every year. Machinery changes alone are not enough to combat these problems; the need for rigid quality checks at every stage is growing as cotton grade, colour and preparation deteriorate.

The fact that raw materials represent a comparatively high proportion of the selling price of coarse goods is of distinct advantage to the mill with quality control. The reaction of alert top management to controlled quality is a lower grade and so cheaper raw material, if competition can be met with the same or a very slightly improved product. Such a deliberate change means a renewal of effort to bring processes back within agreed tolerances; superficially, the effect on those in the mill may be discouraging. Ten minutes with a blackboard, to show only one calculation, can provide a stronger argument for quality control than voluminous books on the subject. The calculation is annual production times the decrease in unit cost per pound, even if the decrease is but a fraction of a cent.

Checks, not Inspection

Quality Control in a coarse goods mill has many points of similarity with other mills, but there are also marked differences in emphasis and allocation of the time of Laboratory personnel. The chief difference is in the matter of inspection; in the coarse goods mill it becomes a routine of testing in early processes by spot checks, rather than a separation of those end products which fall outside acceptable standards. Burling, mending, dyeing, and finishing are operations which are rarely performed on coarse goods; such products must be top quality when they leave the loom. Attention is concentrated, therefore, on early processes. Many mill men maintain that "good yarn is made in the Picker Room", and few coarse goods manufacturers will contest this principle.

To illustrate: a length of duck whose construction includes filling of 7's yarn four-ply will be accepted by the customer even though the average filling yarn count may be actually 7.2. If, however, the selling price is based on the weight of a specified length, the

dollar return to the company is 3% less than the order warranted.

Accordingly, many of the advantages of a Q. C. program accrue from frequent routine testing of sliver and yarn sizes, as well as lap, sliver, and yarn evenness variations. From statistical analyses of the data, long-term changes in settings are proposed and trends are determined; short-term or immediate changes result from daily checks.

Here the importance of the "management by exception" policy is readily apparent. Intelligent standards, frequently revised, are essential. The level of personal relations between the "contact-man" of the Quality Control department and production department heads must be of the highest order, or every attempt to revise quality limits is destined to end as a time-consuming argument in the manager's office.

The above references to the value of sizing and variation checks does not preclude the need of routine testing of such variables as speeds, package sizes, tare weights, trumpet sizes, and running breaks. Often required as well are impartial tests, occasioned by changing raw material or by proposed machinery modifications. A true cloth grading procedure is initiated for few of the lines in a coarse goods mill, for the reasons outlined above.

Control Personnel

The number of employees on full-time Quality Control work is established by recognition of a variety of determining factors--such as the number of spindles in the mill, humidity conditions, variations in quality of raw stock, testing equipment authorized, mill policy on centralization of preventative maintenance, and exhaustive consultation with line personnel on the very important question "How much information is needed to maintain consistent quality at each process?" Before a formal program is introduced, the answer to this last query should be based on a preliminary survey to point up the relative needs for quality assistance.

Too often overlooked is the importance of periodic surveys to revise these relative needs from three standpoints: raw material, machinery, and human. A popular business cliche is that if an operation has been done the same way for a year, it is due for a change. Nowhere is this more apt than in Quality Control.

The following break-down shows a typical distribution of the time of control personnel:

Weight Variations (picker laps, card and drawing sliver, roving, yarn)	22%	
Moisture Regain (raw material, picker laps)	15%	
Linear Variation (card and drawing sliver, roving)	10%	
Breaks (drawing, spinning, warping)	10%	(a)
Yarn Strength	8%	
Machine Speeds	5%	
Hopper and Spindle Idle Time	5%	
Card Neps and Waste	4%	
Cloth Strength	3%	
Supervision and special tests	10%	
Other	8%	

(a) Carding and roving breaks determined by Time Study Department; loom stop record kept periodically by weavers, checked by T. S. Department.

A corollary function of a separate Quality Control Department is its provision of a training ground for supervisors. The coarse goods mill, especially the small or medium mill, has very few staff or line jobs which cover all operations; the Q. C. Lab may be staffed with training as one objective, and annual changes in staff made in accordance with the overall supervisory training program.

Waste Control

Waste control is particularly important in the coarse goods mill because the weight of material produced per minute of machine run time is comparatively high. The cost per minute of any machine putting out material which is classed as waste is accordingly expensive, and rigid control (no other term is truly descriptive) must be maintained.

There is, of course, a minimum percentage of waste which must be extracted--particularly in those processes which are grouped in under the general heading "Carding". Determination of this optimum varies with the quality of raw material, extractive powers of the machinery, and the often-debated "How clean is clean?"

With natural fibres the amount of waste varies with every bale, so rapid response to such variations is vital if standard percentages are to have any practical meaning. An integrated program which combines Buying and Waste Control may be justified if raw material quality ranges widely, and frequent changes in machinery settings may be warranted.

PRACTICAL QUALITY CONTROL IN MOTOR ASSEMBLY AND MACHINING

Robert O. Tapler
Chrysler Corporation

When I was first asked by the heads of the Automotive Division to present a paper for this National Convention, I began to shudder. For through my mind flashed sigma's, $\bar{X}$-R's, $\bar{P}$'s, and other mathematical voodoo with which many readers would be more familiar than I. But after reading the convention program and noting all the excellent writers that would be relating their experience in statistical theory and the like, I thought that some of you would be interested in the "on the firing line" approach to Quality Control. In other words, the production supervisor, worker, inspector aspect.

In our case at the Chrysler Division this had to be the approach, because our Management insisted that any program which would be initiated in our Motor and Machine Division had to be practical.

"Let's be practical" were their exact words. How many times each day do you hear that expression, especially from the good old experienced managers. I know that all the new high power technical groups that are infiltrating industry are hearing it often.

Let us define this word "practical". The dictionary says it means pertaining to or connected with ordinary activities, business, or work. So we must take a so called extraordinary technique like statistical Quality Control and apply it to the ordinary activities on the firing line, the machines, workers, the backbones of our plants.

We embarked on this venture over four years ago, and in two years had brought our engine to the top of the quality parade at a considerably lower cost due to greater efficiency and scrap and rework reductions. This has been achieved even though only a handful of personnel in the plant understand a little of sigma's, $\bar{X}$-R's, $\bar{P}$'s, etc.

Now I would like to present to you a general picture of our program: "Practical Quality Control in Machining and Motor Assembly". Naturally, assuming the theme, "the best quality engine at a cost to show a reasonable profit," we set up the following objectives with prevention of defects the basic purpose of the program. They are:

1. Planning the action.

2. Determining our losses.

3. Coordinating the program.

With these objectives in mind we started into the machined parts division. It consisted of three control projects:

1. Initiation of a weekly quality meeting.

2. Changing of a weekly quality inspection into a daily quality inspection.

3. Closer analysis of scrap and rework.

The weekly quality meeting is composed of Service Department heads, Production heads, and also our Works Manager. We started out by having Production submit a list of all operations or dimensions which were causing them trouble through loss of efficiency, scrap, rework, or quality. Yes, I will admit that the list was pretty long, because as you well know, people will tend to push their problems on to someone else and our Production men are no different.

Next there was in operation a weekly quality inspection on all parts and all dimensions. This consisted of five pieces being inspected one day a week and each week a percent defective calculated for the part. There were always complaints from Production stating that the inspections were being made the one time during the week that they were having trouble. We changed the inspection to one piece completely inspected the first half of each shift and one piece the second half of each shift every day to eliminate this complaint.

The percent defective was calculated each week for the part. The foreman was asked to write on the back of these quality inspection sheets what action was taken to correct the defective dimension if it appeared more than two times each week. See Fig. 1 for sample of Quality Inspection Sheet.

FIGURE 1

V-8 CYLINDER HEAD (CHRYSLER) 1634691 DEPT. 97 TOTAL DEF._____

FOREMAN_____SHIFT_____ POSSIBLE DEF._____

INSPECTOR_____DATE_____TO_____QUALITY_____

INSTRUCTIONS: Inspector should check two finished pieces, one in the first and one in the second half of the shift. The checking procedure is as follows: (1) Check the very first piece selected and record as OK only cleanly OK pieces. (2) Mark as defective, any piece which is either in doubt or definitely defective. (3) Production Foreman will investigate every defect and correct the condition. (4) Production Foreman will state the nature of trouble and the specific steps taken to prevent recurrence, whenever two or more defects occur on any one item.

NO.	DIMENSION	TOT POS DEF	GAGE	MON		TUE		WED		THUR		FRI		SAT		NO. OF DEF.
				1	2	1	2	1	2	1	2	1	2	1	2	
	Depth of S/Plug Hls.	4	R-12													
	Loc of Push Rod Hls	8	R-10													

Last, the scrap and rework were put in graphical form, detailed, and analyzed.

We were now getting a quality picture so our progress could begin. Utilizing two Quality Control engineers and a number of roving inspectors (these men were under Inspection Department supervision) we initiated $\bar{X}$-R or $\bar{P}$ charts of various forms on the most troubled items and began getting data. More complex tests were made personally by the Quality engineers. I might add at this point that the success of the program was helped a great deal by the engineers' willingness to make inspections, get themselves dirty, and learn the way of the workman rather than stand back or sit up in an ivory tower. This showed the people in the plant that we were sincerely interested in helping them.

Now, when a quality meeting is held; and as each problem is brought up it is assigned by us to the responsible parties, either Production, Master Mechanic, or Inspection.

It is ironical to note that initially Production brought in all their troubles which they could not control. Many of our investigations proved otherwise, so the responsibility for cleaning their own backyard was given back to them.

The Master Mechanic Division was also criticized at the offset. They would be assigned a problem then go down on the job, make a change, check one piece, and report back that the job was okay. Subsequent checks by our department revealed that the problem still existed. They soon began contacting us for help and eventually came to rely on us for solution to many of their problems.

The Inspection Department was assigned the responsibility for any incoming material problems. They soon requisitioned our help for sampling methods.

Our Engineering people were completely sold on our approach. When we submitted data and facts to them on why a tolerance change is needed, 99% of the time a change is forthcoming. This was a far cry from the old requests for tolerance changes of "production cannot hold", which Engineering usually ignored.

Of course there were times when operations didn't improve as fast as we would have liked, and we became overzealous in our statistical approach to some of the people. I would like to cite two particular examples.

We had a $\bar{X}$-R chart on an operation in our camshaft line, a line composed of our oldest seniority workers. The analysis of this chart showed that they were producing a percentage of defective shafts. One of our engineers started to explain to them the out-of-control points, "No, we're not taking away any of your tolerance, etc.", but we couldn't show them any defective pieces in our samples. Our progress was stalemated until we changed the $\bar{X}$-R chart to a $\bar{P}$ chart. In a very short time the defects began showing up. They quickly changed their methods and the job was corrected. This enlightened us to such a degree that $\bar{P}$ charts are the only ones used in our plant except for special studies.

The other example was in our rocker arm department. We had 100%

inspection on this part at the end of the line. After process studies and corrections were made we proposed an acceptance sampling plan at the end of the line. One man part-time replaced five inspectors and the plan worked beautifully. Any rejected lots were inspected 100% by Production. Later a change to acceptance variable sampling was made. We reduced inspection time and number of pieces inspected, and were rather insistant in keeping this plan. But, the troubles which were encountered through the complexness of this plan for the Inspection Department were so great that it was scrapped for the original sampling plan.

In the last two years many refinements have been made in our machine shop. All hundred percent (100%) inspections have been replaced by acceptance sampling methods or no inspection, except on three parts which require grading because of final assembly requirements. Our Daily Quality Inspections and Scrap are being put out in pyramid controlled reports based on the principle employed at General Electric. (Article - Industrial Quality Control Magazine - October - 1955) See Fig. 2 for General Superintendent Scrap Report.

FIGURE 2

WEEKLY SCRAP SUMMARY
MACHINE DIVISION
CHRYSLER DIVISION

No Color - Normal
Red Color - Deterioration
Green Color - Improvement

Month- June 1955
General Superintendent- J. Howard

$\bar{P}$	WEEK ENDING									
	SUPT.	RESP	DEF	PROD	DEF	PROD	DEF	PROD	DEF	PROD
1.2	John Doe	Mach.								
.6		Vend.								
1.2	Joe Doakes	Mach.								
.8		Vend.								
1.0	TOTAL	Mach.								
.6	TOTAL	Vend.								

The old reliable quality meeting is now held once every three weeks and deals mostly with new or re-designed parts and operations.

The second part of our program was our vendor material which gave us trouble in the field or in our dynamometer check. The Mil-Std plan was installed with slight modification and our vendor performance tabulated on punched card equipment.

This report listed the following:

1. Part number.
2. Vendor name.
3. Receiving Inspection area.
4. Inspection plan used.
5. Vendor's A. Q. L.
6. Total amount received.
7. Disposition of total amount received.

A - Accepted - Conforms to specification.

B - Accepted - Non-conform - use as is, pending specification change.

C - Accepted - Non-conform, non-critical, requires extra work.

D - Accepted - Non-conform, critical, requires extra work.

E - Accepted - No inspection.

F - Accepted - Non-conform, non-critical, use as is, emergency, (prevent shut-down, etc.)

G - Accepted - Non-conform, critical, use as is, emergency.

H - Rejected to Vendor-Non-critical.

I - Rejected to Vendor-Critical.

You can see that this report can be utilized very effectively by Purchasing, Planning, and Inspection.

The last part of the program in our Engine Assembly Section could finally be started. The key to our problem in this area was at our engine test stands. This was where our standards had to be set, and where our feedback was initiated.

Let me familiarize you with our processing. The finished engine

arrives at the test stands. One inspector covers so many engines and passes judgment on them. The okayed engine proceeds to car assembly; while the rejected engine goes to an engine repair section where it is repaired and returned through the test area for okay. The engines which were okay and assembled into cars and later rejected at the tuning rolls are sent to a heavy repair section.

A thorough study was begun at each one of these areas, test stand, engine repair, and heavy engine repair. This study revealed that there was no organization as to assignment of responsibility. We set about to initiate the following procedures:

1. Tally sheets at engine and heavy engine repair sections.

2. Inspector's responsibility charts in each inspection area at the test stands. They were put up after Production, Inspection, Engineering, and we determined what defects these inspectors could be held responsible for. This is essential because different type test stands will change the inspectors responsibility.

The engines which were rejected at the tuning rolls are sent to heavy engine repair. The defects and the inspector's number are tallied, and the items which the inspector should have caught are recorded daily on the inspector's responsibility chart. At first, these charts showed a varied picture; but after education and cross competition the group began working in unison, and now very few defects are missed. Remember, don't hold the inspector responsible for items uncontrollable by your equipment or methods. The major defects tallied at engine repair were fed-back to the responsible parties, Production or Inspection. $\bar{P}$ charts were set up in the Motor Assembly area and this control quickly reduced our repairs.

Today our function is merely to summarize the repair sections' tally sheets and publish a weekly report with control features to Management.

This is our program, "Our Practical Program". It has been successful in our plant, and many of the ideas have been successfully utilized in other divisions of the corporation. I hope you haven't gotten the idea from the theme of this paper that our Quality Control Department is not an ardent supporter of statistical methods. This is not true. We had a job to do of improving quality and saving money, not educating people on statistical methods.

MODERNIZATION OF TIRE QUALITY CONTROL

Russell W. Glenfield
Dominion Rubber Company Ltd.

The success of any business depends upon quality of service of the goods that it produces. In the post war years with the trend to higher horsepower cars and higher speeds, it has become increasingly important for tires to be of high and uniform quality in order to give the required service.

Quality cannot be inspected into a product; it must be built into it at every stage of the process. This familiar saying is very well suited to the rubber tire industry. Final inspection will sort out tires with obvious surface defects, but it will not eliminate those tires which may be weak due to some inner defect. Once a tire has been built and cured there is no way of probing the inner components to determine whether the tire has some hidden defect or has been built with some off specification component which will effect the service of the tire.

Dissection and examination of finished tires are carried out and are very valuable in determining finished tire quality and estimating the service performance. However, unfortunately only a very small percentage of tires may be tested in this manner.

Accelerated laboratory and road testing of tires also gives us some insight into the level of finished tire performance, but of course, this again may only be carried out on a small percentage basis. Even these tests are lacking in the respect that they may not show up defects that may take months or years to show up in service.

Our company spends large sums annually on research and development to determine the best tire compounds and constructions. Similarly large expenditures are made to purchase the latest machines and equipment to improve tire quality. The full benefits from these cannot be realized, however, without good control of quality throughout the manufacturing process.

Therefore in a rubber plant it is necessary to control the quality of the tire components at each stage of the manufacturing process. Only if each process is operating within safe tolerances can we be assured that the finished tire quality is satisfactory.

In 1945 it was realized that our quality control program would have to expand and improve, and statistical quality control methods were introduced at that time to the factory organization to help accomplish this.

Statistical methods have resulted in a great improvement in our quality control. Our quality checking has been streamlined and our quality control coverage has been expanded. Large savings have been realized through reduction in defects, rework and over stock useage. At the same time statistical methods have resulted in a greater assurance that the finished tire quality is as desired and will remain so.

The application of these methods to factory processes and the acceptance of these principles by factory personnel was a long slow process. However, we feel that we have made very good progress.

Fig. 1 - Sample Elongation and Sp. Gr. Chart

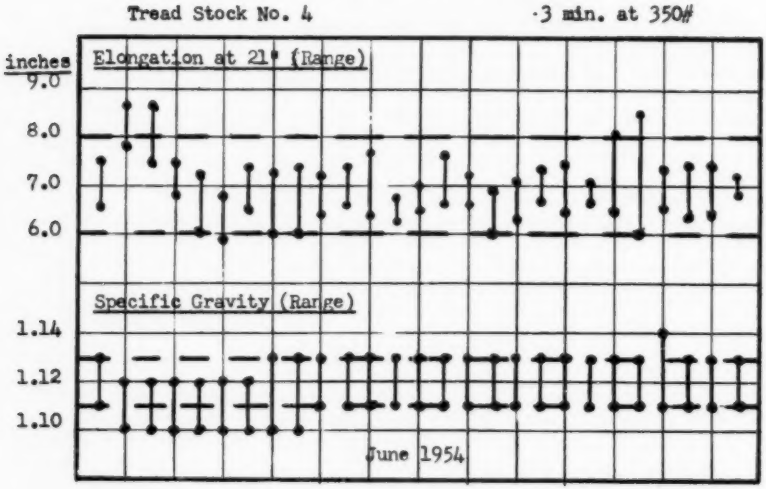
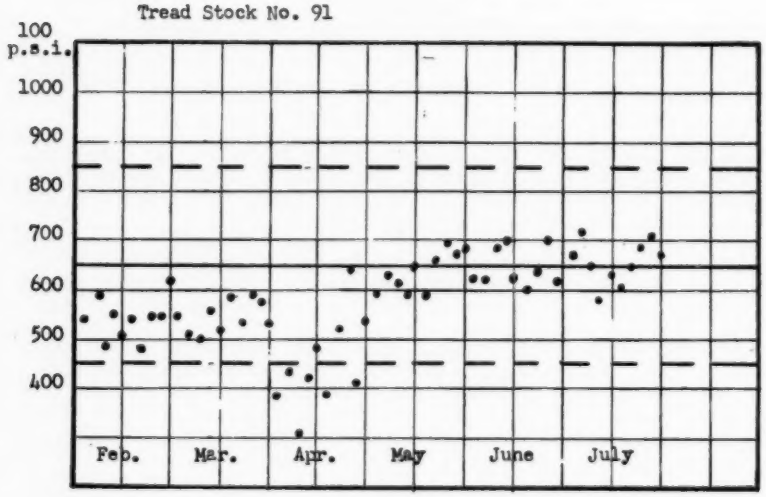


Fig. 2 - Sample 300% Modulus Chart



One of the first steps in introducing S.Q.C. methods here was an intensive educational program in 1946. These training courses were given to all technical quality control, and production supervision. These courses were later repeated in 1952.

At the present time we are making wide use of chart control techniques in both the factory and the laboratories. It is the purpose of this paper to show a few examples of these applications and to illustrate how statistical methods have helped to modernize our quality control.

1. Control Testing of Stock Compounding and Mixing

We currently use about 200 different types of stocks in our Millroom. Most of these stocks are mixed in Banbury Mixers in batches of approximately 450 lbs. All batch ingredients such as rubber, carbon black, sulphur, accelerators etc. are added according to a certain specified recipe.

One of the oldest and most important control tests has been the testing of these batches to ensure that no defective batch gets through to subsequent processing. Miscompounding or changes in raw materials may cause mixed batches to be defective for cure rate, colour, appearance etc.

Q.C. inspectors take one sample from each batch of rubber mixed. The sample is cured and tested for cure rate and specific gravity. Through the years this has remained basically the same. The method of testing and recording this data however, has been improved.

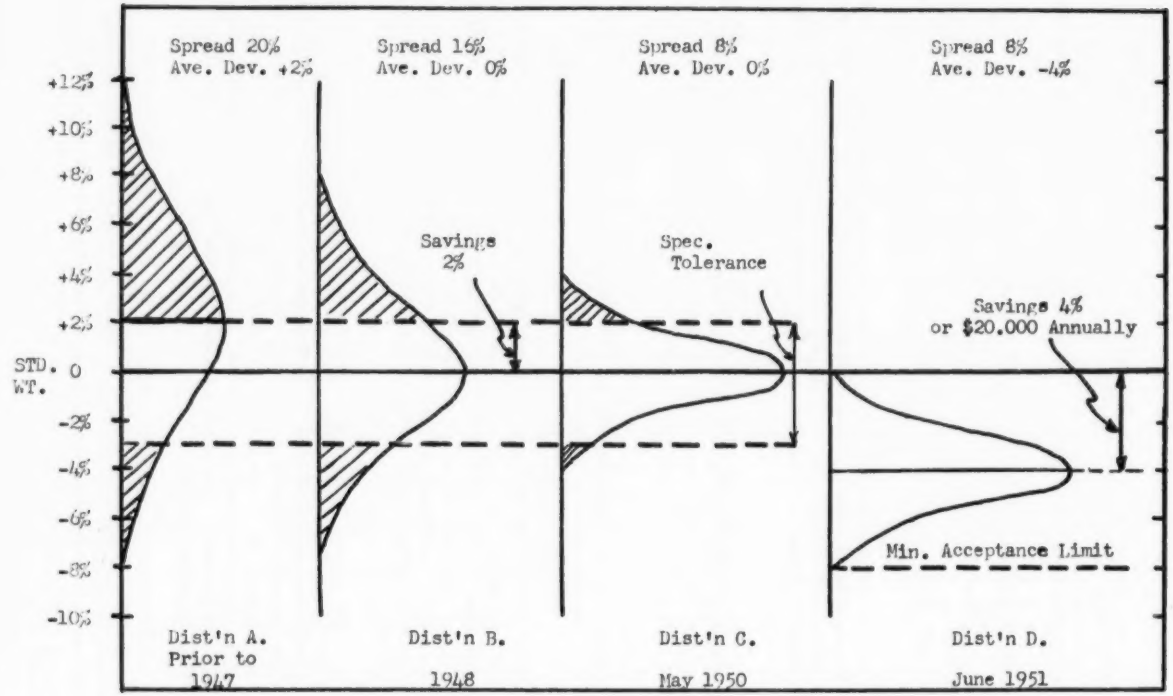
Prior to 1946 each cured sample from each batch of stock was checked for hardness by Shore Durometer and for specific gravity. Hardness and specific gravity results were recorded on a long sheet in tabular form along with the specification tolerances for each stock. In 1946 we improved this greatly by simply recording the test results in chart form. One chart was set up for each type of stock plotting the average and range for hardness and specific gravity results of each successive group of six batches. The advantage of this was that it gave us a running history of each stock. It made it much easier to detect trends in stock cure rates and correct for same before serious trouble occurred. Also it showed up the most troublesome stocks and where the corrective action was most urgent.

In 1952 it was found that elongation of a stock was a more sensitive measure of cure rate variation than hardness. As a result at this time we replaced the hardness test with the new elongation test for checking of mixed batches. This test consists of measuring the inches elongation that takes place in a cured dumb-bell of stock at a predetermined stress. We continued to use charts to record elongation and specific gravity results of each stock. Figure 1 illustrates the type of chart that is used currently in this testing.

In 1954 the weigh scales used by the production compounders were improved and converted to the print weigh type. The print weigh scales give us a permanent record of the actual weights of compounds in each batch. This has been very valuable in cutting down the number of compounding errors thereby substantially reducing the number of defective batches.

In summary, then, the improvements made in testing of mixed stock

Fig. 3 - Improvement in Tube Weight Distributions



have been: the use of charts for better interpretation of test results, improved testing methods, and the use of print weigh scales.

More critical tests such as modulus, tensile, and elongation are also carried out on all types of stocks. These are much better tests in that they give a more complete picture of the physical properties. However, as these tests are more time consuming, the frequency of sampling must be more restricted.

Prior to 1946, stocks were tested for tensile, elongation, and modulus only when there was a change in a stock or when factory trouble occurred. In 1946 a system of sampling and testing of each type of stock was set up on a definite routine basis. At the same time we started to record results in chart form having a chart for each property measured of each stock. These charts have been found to be very valuable in maintaining control of stock physical properties. They serve as a valuable record of test data. They result in faster corrective action. By showing up trends in the physical properties, they give a forewarning of impending trouble. Thus they help to eliminate troubles before they actually occur. Figure 2 is a sample of a modulus chart used. Note the correction that was required in month of April.

2. Tube Weight Control

By controlling tube weights, one indirectly controls tube wall gauge. Tube weight and gauge are dependent upon and controlled by the tube extrusion process. Our tubes are extruded in a continuous circular form then precut to a specified length before splicing. Production operators are supplied with weight and gauge specifications for all sizes of tubes. The objectives of weight control are: (1) to produce as many tubes as possible within the weight tolerances specified (2) to avoid excess useage of tube stock and keep costs to a minimum.

Before 1947 tube weight sampling and checking was done by the preparation production operators. Records showed almost all tubes within tolerances. Yet stock records continuously showed an excess useage of tube stock over standard.

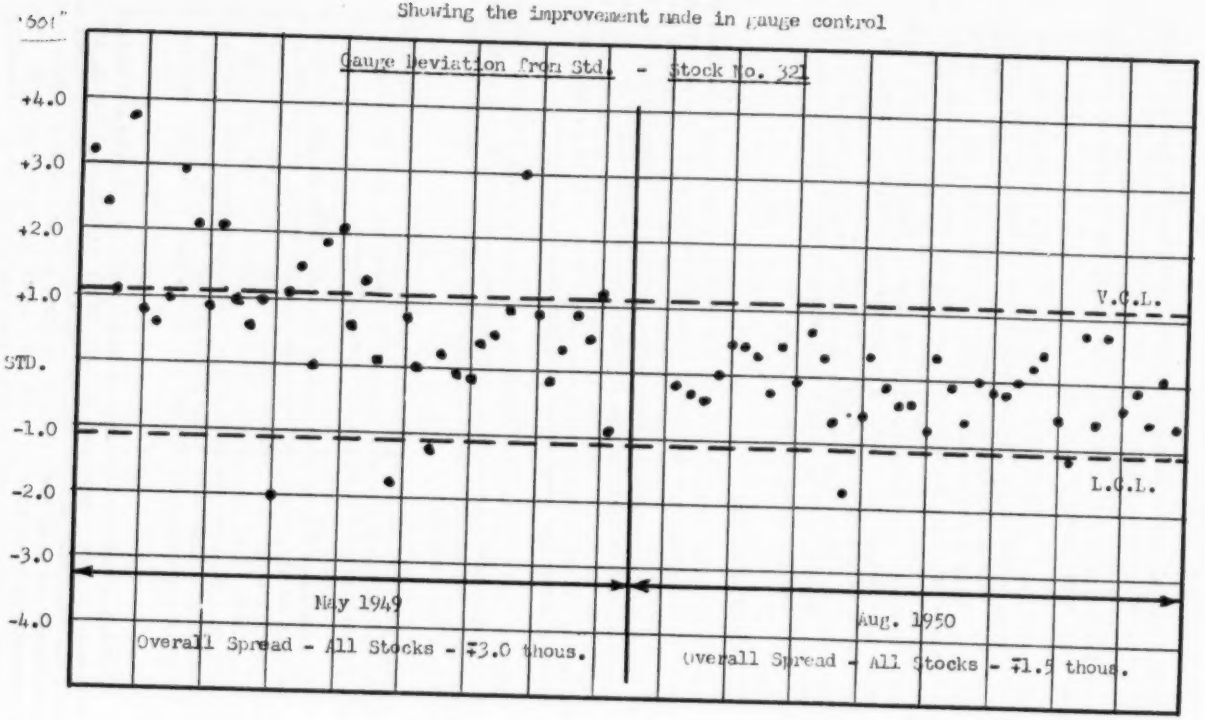
This prompted an investigation by the Quality Control Department, and in 1947 an inspector was assigned to sampling and weighing of a small percentage of all sizes of tubes produced.

An analysis of this data showed that the tube weight picture was not as rosy as it seemed, but was running according to distribution A shown in Figure 3. The average weight of all tubes was found to be 2.0% over standard. Individual tube weights ranged all the way from 8% below standard to 12% above standard for a total spread of 20%. Specified tolerances at this time were quite rigid at -2% to +3% for a total of 5%. As a result approximately 50% of all tubes were above the maximum tolerance.

Further investigation showed that the cause of this overweight was a shrinkage of the tubes upon cooling after extrusion. During the next year this shrinkage was determined exactly for all sizes of tubes and allowances were made for it in processing specifications. This corrected the overweight condition as shown in Figure 3, distribution B. The result was reduction in excess tube stock useage of $10,000 annually.

Fig. 4 - Skincoat Gauge Chart

Showing the improvement made in gauge control



We next went to work on tube weight variation. Charts were posted daily showing tube weight results of each tuber operator. A thorough analysis was made of the variables causing weight variation such as, tuber set-up, raw scrap work-off, blending stock, weight checking done by tuber operators. By May 1950, variation had shown a good improvement and for this particular month we were able to run to an 8% spread in one popular size tube. Also theoretical control limits worked out to an 8% spread. It was at this point that we decided that the specified tolerances (-3% to +2%) were too tight. The Specifications group were then asked to set more realistic tolerances. The outcome of this was the decision to specify only a lower tolerance and this would be considered as a Minimum Acceptance Limit. This was set at 8% below the present standard and was known to be satisfactory as far as tube service was concerned.

The purpose in setting only a minimum tolerance provided an incentive to the tube department to reduce tube weight spread. By reducing spread they could lower their average weights and reduce tube stock useage accordingly.

By June of 1951 overall tube weight spread was reduced to 8%. This enabled us to run according to distribution D in Figure 3. With the reduction in spread to 8%, we were able to reduce average tube weights by 4%. This resulted in a further reduction in tube stock useage amounting to $20,000 annually.

In this case, our improved quality control resulted in reduced tube weight variation, a larger percentage within tolerances, plus the added benefit of better control of stock useage.

3. Calendered Stock Thickness Control

In the processing of plies for a tire, the fabric must be coated on both sides with a thin sheet of rubber. The thickness of the rubber sheet is in the order of .010" to .030" depending on its use. This sheet is applied to the fabric on a calender and the sheet of rubber is referred to as a skimcoat.

It is very important that there be very accurate control of this skimcoat gauge. First, since the skimcoat gauge is quite thin, accurate control is necessary for good carcass performance. Second, since most of the skimcoating for all tires is done at the one calender the total useage of stock is very great amounting to several million pounds annually. Thus good control is needed for control of stock useage.

In 1945 our Quality Control Department first started an investigation into skimcoat gauge variation. At that time calendering was being done on a 3 roll calender. Operators were using Waltham type dial gauges to measure stock thickness on the roll. It was soon found that these gauges were not accurate enough for the degree of control we desired and we devised a weight method of calculating gauge.

By weighing a known area of the skimcoated fabric and subtracting the weight of the fabric, we were able to arrive at the skimcoated deposit weight per square yard. This was then converted back to gauge and results were accurate to ±.0002". A system of sampling was set up and carried out by Quality Control inspectors. Results were plotted on a chart posted at the calender. The calender operator was educated to use this chart to

help him adjust his calender and strive for the specified gauge. By 1947 the variation in gauge had shown a 50% improvement from an initial ∓.0030" spread to a ∓.0015" spread. This control was useful in showing up the inadequacies of this older calender.

In 1948 a new 4 roll calender was installed. It was equipped with four Magnetic type Schuster gauges. These were a new type gauge capable of indicating the stock thickness on top and bottom rolls to the nearest .0002". However, it was soon found that these gauges were not foolproof. These gauges indicated a deviation from standard and were dependent upon the calender operator setting the correct standard point.

So once again we resumed our weight checking of the skimcoated fabric. This was done by sampling of skimcoated fabric in the form of plies at the bias cutters. From the weight of the ply we were able to determine very accurately the actual skimcoated stock gauge. We found that gauge variation was again excessive at ∓.003". By continual checking we reduced this variation by 1949 to ∓.002".

In 1950 recorder charts were installed on the Schuster gauges to give us a continuous record of performance. These recorders showed us that the Schuster gauges were effected by changes in ambient temperatures. When we made allowances for this we were able to make further substantial decreases in variation. Overall spread was reduced to ∓.0015".

We are still using this weight method of determining skimcoat gauge and use it as a check on the Schuster gauge settings. Figure 4 is an example of a factory chart on this and indicates the improvement that was made in skimcoat gauge variation from May 1949 to August 1950.

These are but a few examples of some of our quality control applications. Actually we have many more quality control check points throughout our plant too numerous to mention here. The control of quality in our plant involves the following:

1. Acceptance testing and inspection of raw materials.
2. Qualitative testing of materials in process.
3. Quantitative inspection of material dimensions or conditions.
4. Qualitative inspection of materials in process.
5. Finished product quality inspection and testing.
6. Process and product specifications.

The statistical method is a powerful tool with which the rubber industry can gain greater finished quality assurance. The only way to obtain a high quality product and to maintain a high quality product is to know that it is being made within safe tolerance bands throughout its processing. The only way to know this is through a knowledge of the manufacturing process and through statistical control of the process. Control charts have been found to be an indispensable aid to this control and have provided a permanent record of the effectiveness of it. Finished product inspection and testing is then used not for sorting the good from the bad; but for assurance that the required quality is being maintained.

SELECTING AN EFFICIENT SAMPLING PROCEDURE FOR FOOD PRODUCTS

Amihud Kramer
University of Maryland

With a few notable exceptions, sampling procedures based on statistical principles are innovations in the food industry. Although some unique problems are encountered, the basic principles and the coverage is similar to that required for any other manufacturing process. Thus samples are drawn to evaluate the quality of: 1- incoming raw materials and supplies, 2- process variables, and 3- finished product.

Sampling by attributes

Since attributes procedures are relatively easy to apply, the first decision to be made is whether the specific problem lends itself to an attributes procedure, and if so, will the inevitable loss of efficiency resulting from the use of attributes criteria be compensated for, by the gain in ease of application. The prerequisites for the use of procedures based on attributes criteria may be summarized as follows:

1. The lots sampled may be rejected if they do not pass rigidly established acceptable quality levels.

2. Test procedures are not time consuming.

3. Test and sampling procedures are not destructive.

Where the above prerequisites are met, procedures such as those described in Military Standards 105A (1) may be used. Some typical examples of situations where attributes criteria are applicable are listed as follows:

1. Sampling of supplies other than raw food materials, such as cans, glass containers, cartons, labels, etc. For an example, refer to paper by Weimerskirch and Way (2) included in these proceedings.

2. Sampling of raw materials for critical defects which would render the finished product unsalable, such as insect or rodent contamination which could not be eliminated entirely from the finished product. For example, a contract between a grower and canner of sweet corn requires that the grower spray the growing crop when necessary to prevent excessive insect infestation. It had been agreed that lots of raw corn delivered to the canning plant may be rejected if the percent of ears infested with insects exceeds 4.0 %. The corn is delivered in truck or trailer loads of approximately 5000 ears. Using a single, normal inspection level as shown in Mil Std. 105A (1), 225 randomly selected ears are inspected visually, and the load is accepted if less than 17 ears are found to be infested.

3. Minimum fill control. A weighing scale may be set at the minimum fill weight, and underfilled units counted rapidly. Although additional information and/or a smaller sample would be required if actual

weights were taken, elimination of the need for recording individual weights, and the calculations involved, may justify an attributes procedure.

4. Sampling for visual defects of the finished product. For example swelled or dented cans, chipped bottles, torn labels, etc.

Sampling by variables

Unfortunately most sampling problems with foods do not lend themselves to solution by attributes criteria. In many situations there is no opportunity to accept or reject lots. Rather the quality level is determined, and payment is made on the basis of a predetermined sliding scale. In such situations variables criteria must be followed. Furthermore, test procedures are usually time consuming, and destructive of the test material. In these instances the sampling error must be estimated for each commodity at the point of inspection in terms of the standard deviation, before sampling schedules may be established on the basis of the precision desired and the cost involved.

Bulk sampling

Where the unit size is small, as in the case of a car-lot of grain, or the material is liquid or semi-liquid, as in the case of a batch of preserves, some discreet unit must be established, such as the contents of a probe, or the volume of a container. The variability among these individual discreet units within the lot may then be determined in terms of the standard deviation. Where the units are of substantial size, as in the case of ears or corn, variability among these individual ears may be determined in terms of standard deviations of the test values that are obtained.

A quick, approximate, method for obtaining an estimate of error in a lot is presented as follows:

1. Obtain at random ten units from the lot, and test each unit by the prescribed test procedure.

2. Calculate the error term (approximation of 2 sigmas) in accordance with the following equation:

$$\frac{2\,R}{d_2}$$

Where R is the range, i.e., the difference between the highest and lowest of the ten test values, and d_2 is the factor for estimating the standard deviation from the range, which in the case of ten values (n=10) is approximately 3.

3. Repeat steps 1 and 2 for as many lots as practicable, and calculate the average error term.

4. Determine the number of units which will provide a sample of the desired precision by reference to figure 1.

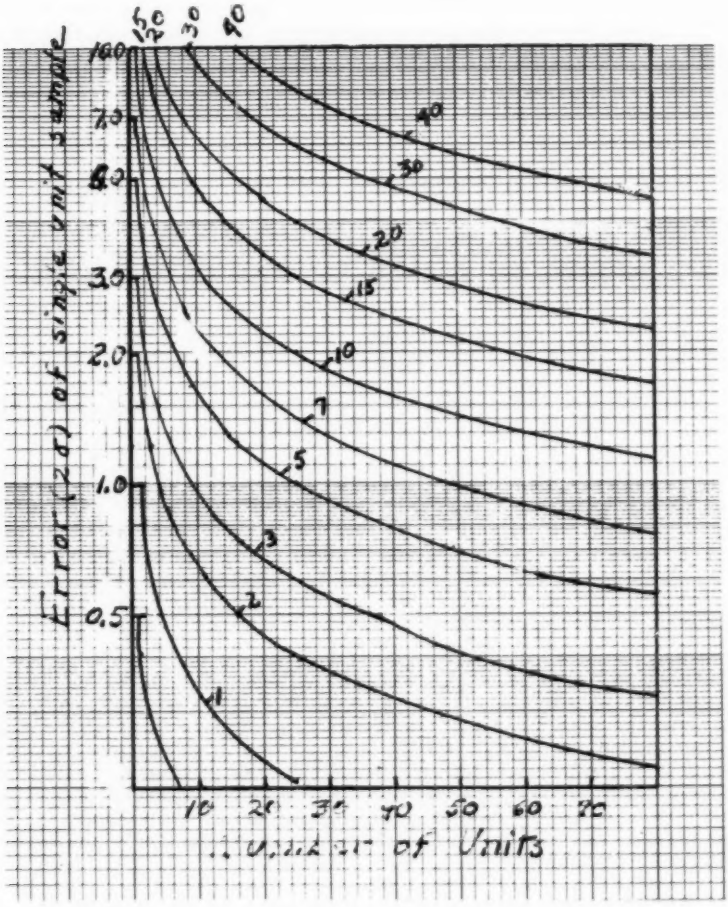


Figure 1.- Number of units needed in a sample in order to reduce the error expected from a single unit sample, to the desired precision

For example, a lot of sweet corn is to be sampled for quality by means of a moisture determination. The problem is - how many ears will

provide a satisfactory sample? The desired precision is 1.0% moisture at the 5% confidence level (odds of 19:1 that test results will not differ by more than 1.0% from the actual mean moisture % of the lot) The analytical error is assumed to be insignificant.

1. Results of moisture determinations on ten ears selected at random are as follows:

ear	% moisture	ear	% moisture
1	73	6	67
2	71	7	74
3	66 - lowest	8	78 - highest
4	72	9	68
5	76	10	75

2. The range (R) among these ten ears is therefore 78 - 66, or 12. Hence,

$$\text{Error (2 sigmas)} = \frac{12 \times 2}{3}, \text{ or } 8$$

Thus the odds are 19:1 that results with a one ear sample will not vary by more than $\pm$ 8% moisture

3. The above procedure is then repeated on five different leads with the following estimates of error: 8 (above), 7, 6, 8, 6, or a mean error of 7.

4. Referring to figure 1, we find that a sample of 49 ears is required in order to reduce the anticipated error to one % moisture.

Sub-lots

Since many food products are handled in sub-lots, i.e., cases, crates, etc., the development of sampling plans for such cases must include a decision as to how many units drawn from how many sub-lots will constitute the most economical sample. It may be assumed that for a fixed number of units, sampling error is reduced, and sampling cost increases, with increasing numbers of sub-lots handled. Thus the problem is to determine at what point does the increasing cost of handling additional sub-lots begin to outweigh the reduction in sampling error. Here again, it is easier, but less efficient, to set up and apply sampling plans based on attributes criteria.

For an example of an attributes procedure we may consider the problem of sampling lots consisting of 600 cases (sub-lots) of tomato paste. Each case contains 48 cans (units). Thus the lot contains a total of 28,800 units in 600 sub-lots. Using the tables provided in Mil Std. 105 (1) and following a single, normal, sampling plan, we find that we need to open 75 cases, and draw 6 cans from each case.

For an example of a variables procedure we may consider the problem

of sampling the raw tomatoes (3). The sampling is for a percent U.S. grade 1 determination. The truck load lots consist of 500 to 1000 baskets with each basket containing approximately 100 individual fruits. Thus the problem is how many tomatoes out of how many baskets will constitute the most efficient sample? The desired precision is ± 3 U.S. grade points.

1. A number of procedures are selected by which samples consisting of 100 tomatoes are obtained (Table 1, columns 1 and 2).

TABLE 1
Relative efficiency of different sampling methods for grading of raw tomatoes for processing (U. S. grades)

1	2	3	4	5	6
No. of baskets	Tomatoes per basket	(s) Standard error	Cost[d] (minutes of labor)	Number[e] of samplings for 3% error	Efficiency[f] index
2	50	6.8	12.0	5.2	62
3	33	6.0	12.5	4.0	50
5	20	5.4	13.5	3.2	43
10	10	4.6	16.0	2.3	37
20	5	4.1	21.0	1.9	40
50	2	3.6	36.0	1.4	50
100	1	3.5	61.0	1.3	79

[d] Cost estimated as follows: 11 minutes required to handle sample of 100 tomatoes, + 0.5 minutes to handle each basket.
[e] Calculated as $N = (s/3)^2$
[f] Calculated by multiplying columns 4 x 5.

2. Duplicate 100 tomato samples are drawn for each procedure from the same load, and U.S. grade determinations made on each sample. This process is repeated for as many loads as practicable.

3. An estimate of error is then calculated as the standard deviation of the differences between duplicates for each sampling procedure (Table 1, column 3).

4. A cost estimate is made in terms of minutes of labor required for obtaining the sample and grading when using the different sampling procedures (Table 1, column 4). Ordinarily the relationship between the sampling error and the number of sub-lots from which a fixed number of units is drawn follows a logarithmic curve, while the relationship between number of sub-lots sampled and cost follows a straight line as shown in figure 2.

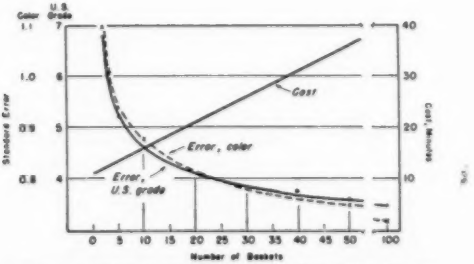


Figure 2. Effect of number of baskets from which the 100-fruit sample is obtained on the error, and cost of sampling.

5. All the sampling procedures may now be reduced on the basis of an equivalent error level, by determining the number of replications required with each sampling prodedure to reach the desired 3% error (table 1, column 5).

6. This value may now be multiplied by the cost estimate (Table 1, columns 4 X 5) in order to obtain the efficiency index (Table 1, column 6). The lowest efficiency index value indicates the most efficient sampling procedure, which in this case is ten tomatoes out of ten baskets. Comparing this most efficient method to the common practice of including all the tomatoes in the baskets selected for the sample, we find that for the 3% precision, only 240 tomatoes from 24 baskets are required, as compared to 800 tomatoes drawn from 8 baskets.

Literature cited

1. Sampling procedures and tables for inspection by attributes. U.S. Dept. Defence, Mil Std. 105A. Govt. Printing Office, Washington, D.C. Sept. 1950.

2. Weimerskirch, R.I., and Ben Way. A mutual approach to quality control by can manufacturing food quality. Proc. A.S.Q.C., June, 1956.

3. Kramer, A., W.L. Ogle, and B.S. Clarke. Sampling procedures for grading tomatoes. Food Technol. VII, 353-355. 1953.

SEARCHING FOR CAUSES OF ABNORMAL VARIATION MULTIPLE REGRESSION ANALYSIS

W. T. Rogers*

Introduction

Statistical methods such as tests of significance, tests for normality, control charts, and various types of sample inspection are designed and used to determine the presence of an abnormal condition in a system of causes. The application of these methods to the routine analysis of production processes in industry is important. They are the means by which it is determined whether or not the process is functioning as expected. Once it has been established that a process is "out of control" or exhibiting an abnormal departure from its usual level of performance the task of searching for the cause of the out of control condition presents itself. Frequently this can be accomplished by physical examination of the process by competent personnel. There are many times, however, when the desired level of a characteristic in the end result is influenced by a number of variables which cannot be evaluated by direct observation. When this condition exists it is quite often advantageous to use the statistical method of multiple regression to determine the source of difficulty.

The object of this discourse is to show how the results of multiple regression analysis can be applied in the explanation of observed differences in an index of rejects on separate production runs of steel product made by the same method on the same production unit. In an integrated production process which starts its manufacturing sequence with basic raw materials there are numerous variables associated with quality in each successive stage of operations. Many of these quality related factors have long been identified by theory, observation, or comparative analysis. This type of identification has its limitations, one of which is that conclusions with respect to the cause of abnormal quality rejects are confined to qualitative rather than quantitative results. Another objection to this approach is that quality related variables in a great many cases are associated with abnormal quality variations only at their extremes and it is not possible to determine the critical range of the variable within which the process must be controlled in order to maintain inspection losses at a minimum. There are also times when one important quality related variable may be at an undesirable level and

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one or more others at a favorable level. When a condition such as this exists there is a possibility that the quality characteristic in the finished product may be considered normal when actually it is not. The multiplicity of quality related variables, each having its own system of causes, makes it extremely difficult in many instances to determine by inspection of manufacturing history the actual range in index of rejects which should be expected. The problem is further complicated by the fact that quality indices and quality related factors frequently do not occur in the form of normal distributions, mainly due to the shifting of the averages from time to time.

In many cases the problem of searching for causes can be solved by application of multiple regression analysis. This type of approach is explained in the following discussion.

The Multiple Regression Analysis

The first step in setting up a multiple regression procedure for the analysis of routine fluctuations in a quality index, is to establish a basic procedure for estimating the relationships between the quality index and the several independent variables. This procedure can take the form of a simple estimating equation provided all relations are found to be linear. Unfortunately, it is seldom that a series of independent relationships is found in which all are linear. An estimating equation describing curvilinear relationships could be developed but the procedure would be more complicated than even a mathematician or statistician would care to use. A much simpler method, and one which presents a picture of the actual observed relationships, is to develop a series of graphs showing the relation of each independent variable to index of rejects separately.

In order to develop these graphs, it is first necessary, either from engineering theory or experience, to decide what variables in each processing stage are likely to be associated with variations in quality and should be included in the study. Once these variables are determined, the next step is to eliminate those which are not suitable because they are qualitative rather than quantitative measurements, dependent rather than independent factors, or highly related to other variables in the study. The remaining variables are then included in a conventional mathematical linear multiple regression analysis from which linear regression lines for the separate independent relationships may be plotted. Each linear regression is

then tested for curvilinearity (1) and the final shape of the regression curves determined by the usual procedure of successive approximation. Each relation is plotted on a separate graph on which is also included the average quality index existing in the data included in the study. From this set of curves the expected quality index for various combinations of values of the independent variables will be estimated within prescribed limits as will be subsequently described. The result of this procedure applied to a limited number of independent variables for purposes of presentation in this discussion is shown in Figures 1 to 6. The captions on these graphs are expressed in steel plant terminology and are briefly explained as follows: Figures 1 and 2 represent two of the chemical constituents of blast furnace iron, manganese and silicon; Figures 3 and 6 indicate relations with chemistry of steel, sulphur and phosphorus; and Figures 4 and 5 represent ingot delivery time from the steel producing facility to the rolling mill and reheating time in the rolling mill reheating furnaces or "soaking pits", respectively. The relations so constructed may then be applied in practice to explain variations in the quality index which exceed the statistical limits of variation established as control limits.

Application of the Regression Curves

The application of this type of regression analysis to the problem of searching for causes of observed difference in an index of rejects or quality index may be demonstrated by the following brief discussion.

Two lots of material were produced on a finishing mill, one of which resulted in an index of rejects of 7.3 and the other an index of .3. The average value of each independent factor included in each lot is then calculated and the averages so obtained were then applied to the corresponding curves and an estimated index of rejects determined. The differences between these estimated indices of rejects and the average index, the latter being shown by the horizontal line, are then algebraically added to the average index. The resultant summation is the expected index for the particular combination of averages obtained in each lot. This procedure together with the expected limits of variation, based on the number of units in each lot and the standard error of estimate within which the actual average would be expected to fall, is presented in Table I.

(1) Refers to reference appended to this paper.

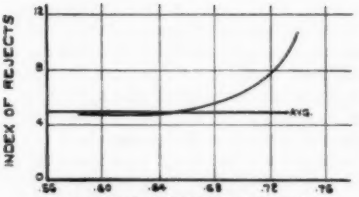

FIG.1 PERCENT MANGANESE IN IRON

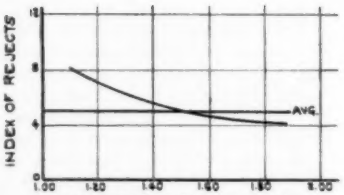

FIG.2 PERCENT SILICON IN IRON

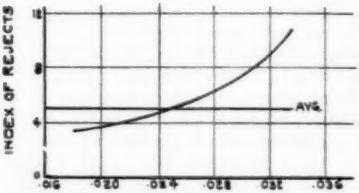

FIG.3 PERCENT SULPHUR IN STEEL

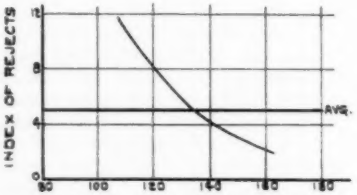

FIG.4 TIME ON TRACKS IN MINUTES

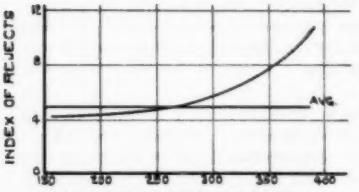

FIG.5 TIME IN PITS IN MINUTES

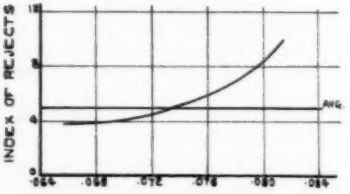

FIG.6 PERCENT PHOSPHORUS IN STEEL

RELATION OF INDEPENDENT VARIABLES
TO INDEX OF REJECTS

TABLE I

	Lot No. 1		Lot No. 2	
	Average of Variable	Adjustment from Curve	Average of Variable	Adjustment from Curve
No. Units in Lot	14		34	
Referenced Average from Regression Study		± 5.0		± 5.0
Average Mn in Iron %	.61	- .3	.61	- .3
Average Silicon in Iron %	1.38	± .8	1.39	± .8
Average Sulphur in Steel %	.026	± .5	.024	- .3
Average Phosphorus in Steel %	.069	- 1.1	.066	- 1.4
Average Track Time Minutes	131	± .8	162	- 3.0
Average Pit Time Minutes	291	± .5	305	± .8
Estimated Index of Rejects		6.2		1.6
Actual Index of Rejects		7.3		.3
Expected 2 Standard Error Range of Actual Index		4.0-8.4		.2-3.0

An examination of this table shows that it is not only possible to select the independent variables which are causing a difference in the index of rejects, but the effect of the independent variables can also be evaluated on a quantitative basis. It is evident that the observed difference of 7 in the index of rejects is due mainly to the difference in the variable designated as track time. It is also apparent that an additional part of the difference is associated with a slight change in the level of sulphur in the steel. Averages of other variables were not sufficiently different to affect the average index of rejects.

Conclusion

The foregoing procedure has shown how the results of multiple regression analysis may be put to practical use in searching for factors in a manufacturing process which may be the cause of variations in quality of product. It is pointed out, however, that this is not the most desirable way in which the results of this type of statistical analysis should be used. The approach presented in this paper makes it possible to determine the cause of an abnormal condition after it has occurred, which of course is too late for practical purposes of process control. The procedure is extended in practice to determine the range within which each quality related variable can be permitted to fluctuate without causing abnormal losses for quality in final product. Once these ranges have been established it is then possible to install a system of control charts from which each variable can be followed on a routine basis and thus control the level of quality in products delivered to the inspection area. Correlation or regression analysis has a definite place both in the search for causes of quality variations and in the setting up of methods for controlling processing variables which are related to quality, so that the occurrence of rejects at final inspection will be held to a minimum.

(1) Mordecai Ezekiel; "Methods of Correlation Analysis" Second Edition, John Wiley and Sons Inc. New York, N.Y.

WHAT MANAGEMENT EXPECTS OF THE QUALITY CONTROL ENGINEER

William J. Masser
General Electric Company

Webster says that "quality" is specifically "an excellence of character" and this is what Management expects of the Quality Control Engineer*. Management expects:

An excellence in knowledge and background which place the Q.C. Engineer's job on a level with the other engineering skills which Management traditionally employs.

An excellence in obtaining Management's primary goals of customer satisfaction and product acceptability.

An excellence in being able to prevent quality errors rather than correcting them.

An excellence in observing the Q.C. Engineer's "Golden Rule": The highest quality product at the lowest quality cost.

General Electric's Q.C. Engineers not only observe this "Golden Rule" but also employ a tested formula: "The Feedback Cycle." Using the Planning, Analyzing, and Measuring elements of this "Feedback Cycle" a system for quality action is set in motion and this "Cycle" provides its own proof of success.

Management begins its Q.C. program with a responsibility to the Q.C. Engineer: to make the Q.C. Engineer - and the Q.C. function of which he is a key part - an integral part of the Manufacturing function and not just a check as he might be if assigned to the Marketing or Engineering functions. Management must also give the Q.C. Engineer the responsibility and authority to operate properly. With a sound organizational position and defined functions, the Q.C. Engineer can put the tested "Feedback Cycle" into operation.

Since the Measurement function of this cycle is performed by Inspection and Test, we will only list the elements of the Planning and Analyzing functions which are the Q.C. Engineer's responsibilities.

The Planning portion of the "Feedback Cycle" includes the establishment of such programs as:

1. "Checking controls" through the entire manufacturing cycle.
2. Quality Assurance gages and equipment.
3. Quality audit ratings at incoming, in-process and final stages.
4. Mechanized and automated inspection-test equipment and paperwork.
5. Vendor quality certification plans.

In the Analyzing portion of the "Cycle", the Q.C. Engineer must do such things as:

1. Design forms to collect quality assurance data that will keep records at a minimum and speed analysis.
2. Facilitate corrective measures based on vendor, complaint, in-process and final product data.

3. Analyze quality cost data to determine direction and application of effort.

The proper performance of the jobs listed above and the many others I have not listed depends upon the accurately defined and compatible relationship which the Q.C. Engineer is required to maintain with his own Manufacturing function and all other functions of the business. Some of the "relation" areas in which the Q.C. Engineer and Manufacturing are allied are:

1. The Manufacturing Method and Process Determination Function which lets counsel and advice flow freely in both directions when Quality Assurance activities are compatible with manufacturing routines.
2. The Materials Procurement Function which selects suppliers in cooperation with the Q.C. Engineer on a "buy it right the first time" basis. In this area the Q.C. Engineer establishes systems which preclude the selection of a poor supplier and gives all suppliers information to enable them to pre-test and pre-prove their product before shipment.

Beyond his "relations" with Manufacturing, the Q.C. Engineer also effects other reciprocal programs, some examples of which are:

1. Design and Product Engineering. By working with this group thru the designing stages, the Q.C. Engineer can advise them and obtain the advance information necessary for him to be prepared for the products arrival at Manufacturing.
2. Marketing. By helping to interpret such things as the quality and acceptance requirements of the customer, estimates on quality control labor and expense, etc., the Q.C. Engineer aids Marketing and gains the reward of mutual aid when marketing must supply him with information on customer complaints. Information from Marketing enables the Q.C. Engineer to judge what degree of quality to build into a product.

Management expects the Q.C. Engineer to employ, when necessary, advanced statistical techniques and apply them. The Q.C. Engineer's abilities in this field increase his value to management as an occasional "trouble shooter" and full-time developments expert. Since the Q.C. Engineer's job is to pre-solve problems, "trouble shooting" should not require any of his major attention. In "development" he can aid management by applying statistical systems to the many manufacturing problems created by automation and mechanization. E.G. In frequency distributions on automated equipment. His statistical abilities are most important in the decision making job of management in areas beyond those resulting from normal analysis of data. Questions like, "What should the ratio of complaint expenditures be to other expenditures?" and "Where can inspection and test effort be best applied?" are examples.

Management needs and asks much of the Q.C. Engineer and measures his contributions in two ways:

1. A Monetary Measure. The Q.C. Engineer should provide Management with a yardstick for this measurement in the form of periodic "Quality Cost Data" reports which analyze this data on the basis of present levels and past trends.

2. A Quality Measure. Here again the Q.C. Engineer provides his own yardstick in the form of an "Outgoing Quality Audit Rating Plan" which indicates the quality of the product being shipped, the adherance to Q.C. rules and the adequacy of the quality plans.

These "measures," while providing a judging standard for management, also serve as the work guides for the Q.C. Engineer.

The growth of Quality Control in the last ten years requires no testimony here. I refer you instead to your own businesses and the increased use that is being made of the Q.C. Engineer in them. Management expects much of the Quality Control Engineer and holds the Q.C. Engineer to the Webster definition of "an excellence of character."

* References made to the Quality Control (Q.C.) Engineer can apply to an individual contributor or to a sub-function of Manufacturing comprised of engineers, specialists, analysts, quality assurance equipment designers, etc.

WHAT ASQC CAN DO FOR THE QUALITY CONTROL ENGINEER

Paul A. Robert
The Gruen Watch Company

Some 74 years ago the first president of ASME, a Professor Thurston said, "He who would accomplish most in the profession of the mechanical engineer, or in the trades, must best combine scientific attainments - and especially experimental knowledge - with mechanical taste and ability with good judgement ripened by large experience. He must be carefully, thoroughly and skillfully taught the principles of his art in the technical school and the practice of his profession in the office and workshop".

This creed for success in the profession of mechanical engineering would seem to fit any branch of engineering and to be as applicable today as it was nearly a century ago. Probably because the engineering societies of this country and abroad have consistently through the years contributed substantially to the professional development of their members, they too have grown and prospered.

It is interesting to note that while the founding engineering societies were firmly dedicated to the promotion of their respective professions, when they failed to provide full opportunity for professional development in a new field, new societies were born.

In 1852, when the American Society of Civil Engineers was founded, the society was conceived as including all fields of engineering not concerned with the military. In 1871, the mining and metallurgical engineers decided that their needs were not fully realized by their association with the Civil Engineering Society so they formed the American Institute of Mining and Metallurgical Engineers.

Later, in 1880, the mechanical engineers banded together to form the American Society of Mechanical Engineers.

In 1884, at a National Conference of Electricians in Philadelphia, the AIEE was formed.

As new branches of the engineering profession developed, the process continued. It was only natural that new specialized groups failed to get the attention they felt they deserved where "large problems remained in the existing areas" and when these groups felt constrained by the inflexibility of policy and did not get proper recognition, that they organized. When the telephone and telegraph engineers who dominated the AIEE had little time for the new field of radio, it was only a matter of time until IRE was formed.

So it was with ASQC. Back in 1940, Dr. Walter Shewhart at a joint meeting of the American Statistical Association and the Institute of Mathematical Statistics suggested to Mr. Edward Schrock and Dr. E. C. Olds that they should take the initiative in calling together a group for the purpose of forming a quality control society. After going through several changes of organization at regional level, it became increasingly apparent that a national society independent of affiliation with existing societies would best serve the needs of the many people who were now interested in the application of statistical methods to inspection. The organizational activities of these pioneers ultimately

in 1946 led to the founding of ASQC.

It appears to be characteristic that when new societies are born, that they open their membership to all who are interested in the new field and that, as the technology associated with the new field develops, the society seeks professional stature for the practitioners of the art. This is a function of importance to all of us in quality control. If the quality control engineer is to achieve the stature of the more established engineering professions, it will come as a result of recognition by our institutions of higher learning that here is a new branch of engineering for which substantial specific training is required.

However, the situation today is somewhat different than 75 years ago when it was possible to cover the entire field of engineering in a few courses. Today, countless new technologies are pressing for recognition in the curricula of our colleges and universities. Today, with the promiscuous use of the word "engineer" in industry it is small wonder that those responsible for establishing the courses of study in our engineering schools are in a skeptical mood when considering the field of quality control. A strong society of practitioners of this new science, exploring, developing, expanding and demonstrating the need of statistical methods in industry will ultimately force recognition by engineering schools. It is not going to be easy and it will probably take many years to accomplish but those of us who have been associated with this movement since its early days cannot help but be confident of its ultimate accomplishment when we look back over the last ten years of our growth and development.

What is this going to mean to you, the quality control engineer? Recognition of the professional status of quality control engineering will define the qualifications of the profession in a business world which is rapidly being inundated with "engineers". Salesmen are now called sales engineers; repairmen, service engineers; time study men, methods engineers, etc., in an effort to dignify these occupations and imply a technical background that often is not there. In the field of quality control, this will not be the case. There will soon be sufficient theory and technology in quality control to warrant its being recognized as a separate branch of engineering. It is up to us collectively through our Society to see that this becomes generally recognized.

It was with this in mind that recent steps were taken to upgrade the requirements for Senior Member and Fellow. There is a need for grade of membership in a professional society to signify maturity, experience and training in the science to those outside the profession.

The continued professional growth of the members of ASQC is as important to the individual as it is to the Society and profession as a whole.

I can think of no better way for the quality control engineer to grow than by association with the leaders in the field. There is little question but that by attending these conventions, reading our journals, and exchanging ideas with others engaged in similar work that we develop ourselves.

As we as individuals develop our knowledge and skill in quality control, we too become leaders and through papers which we present at meetings and submit to the journal for publication, we too help to advance

the progress of ASQC and gain personal recognition for ourselves.

The Society, through its Editorial Board, on the otherhand coordinates this expanding volume of technical material which appears in IQC and other official publications of the Society. The editorial scrutiny given the various papers presented protects the members of the Society against the publication of "unsound" material which could damage all of us professionally.

It is worth a lot to know that the theory or technique being expounded in a paper has been thoroughly reviewed by experts in the field and that you will probably not be embarrassed by its failure to do for you what the author claimed for it. Of course, this does not mean that every new technique published will work in all situations, however, to most of us who do not always understand the derivation of all the formulas and charts we use, it is comforting to know that men of the calibre represented by our Editorial Board are critically reviewing these papers before we see them.

The problem of nomenclature and definition of terms developed quickly as numerous articles and books appeared with a great variety of symbols. The Standards Committee undertook to establish Standards for the guidance of future authors which is no small service to readers who must digest the material. This committee took over the responsibility for the 1.1, 1.2 and 1.3 ASA Standards on Quality Control which were originally published during World War II under the guidance of Mr. Harold Dodge, present Chairman of the ASQC Standards Committee.

In this Committee, we as members have the assurance that as new theory is developed, and new terms and symbols are introduced, that they will be integrated into a standard terminology and definitions. This is of obvious value to all of us who use the techniques and correspond with others in the quality control field.

Another committee whose work is important to quality control engineers is the Committee on Professional Ethics. There have been in the past some members in the Society and others outside our membership who have sought to profit by practices that would have injured the professional standing of the Society and the profession as a whole. The alert and prompt action of this Committee has kept our profession on a high ethical plane. As it grows in stature and reputation as a branch of engineering, it will be indebted to these men for their vigilance and efforts in our behalf. Every quality control engineer proud of his profession wants the assurance that unscrupulous or thoughtless acts on the part of others are not going to cost him the recognition he has worked so hard to attain.

I think the men who formed the Society and have since guided its development also are to be commended for the magnificent job they have done in keeping the channel open between the theoretical statisticians and the practitioners in the shop. This bridging of the gap between the development of new concepts and their application to real problems confronting us in the shop, I know has not been easy. I could not help but be amused at our annual meeting last year when I heard the Editor of our magazine being assailed on one hand for not publishing more papers of professional stature, and on the other for not publishing more papers of a practical nature. He must have left the meeting convinced that he was

right in steering a middle course. Personally, I have always felt that our journal was well balanced, between papers of a practical nature describing applications and those presenting new techniques and theory.

At this point, I should like to quote from a report of Professor Paul Clifford who spent nearly a year in Europe under the auspices of our Government, assisting foreign industries in applying SQC techniques. To quote:

> "The programme in each country has been uniquely developed to meet the needs of that particular country. There seem to be three needs common in all countries. The first is a lack of comprehension on the part of management as to the functions and objectives of quality control in general. The second is the difficulty encountered in bringing the theory down to the operational level that plant personnel can comprehend. The third is the fact that in general no organizations devoted to quality control exist, and communication within a country and between countries is difficult. In each country the programme provided some approach to a solution of these three problems. However, the situation with regard to the level of technical ability within the various countries varied considerably, and the particular type of training programme developed took into account these differences in level.
>
> "It is not feasible to compare the relative status of quality control in America and Europe. In the European countries a great deal of attention has been devoted to the theory of statistics and control, without much attention being paid to the training of plant personnel."

It might be said that the Society, and its publications, have little to offer the theoretical statistician, but we should recall that Dr. Shewhart's original concepts in the field grew out of recognition of a practical problem and not an exploration of statistical theory. The impulse to invention comes from recognition of a common problem. As the need for statistical techniques to help solve the problems which confront engineers in industry, scientists in their laboratories, managers in their offices, comes to light through the exchange of ideas that takes place in personal contact, in our meetings and through our publications, I am sure that those of us who are pioneers in the field of statistics will be inspired to invent new theories and techniques we will be applying in the years to come. So, in the final analysis, all are served by this association we have created.

It has been particularly gratifying to me to see how much our Society has done to break down the barriers that seem to build up between industries, especially competitors in the same field.

Years ago a friend of mine explained that he regarded the developments his company had made in quality control a trade secret because he felt that their ability to control quality more economically gave him a competitive advantage. Just imagine the sorry state we would be in, if very many of us felt as this man did.

Yet, in other fields this is the case, and there exist real barriers that restrict the exchange of information between engineers of competing companies.

Outside of this one case, I cannot recall of any instance where information was not available for the asking and more often than not, more was offered than was asked for.

The friends that I have made in ASQC and their willingness to help me solve quality problems which I have had facing me at various times during the last ten years, I regard as one of the most important benefits I have derived from my association with the Society. It is difficult for me to see how any of us can develop to any great degree without the benefit of professional contact with associates in our field, and there is no more efficient way that I know than being an active member in a technical society dedicated to that purpose.

In addition to providing helpful suggestions, new ideas, food for constructive thought, the periodic shot in the arm we get from listening to problems of others, hearing of a new technique, or reading of a successful application of familiar principles in a new field inspires us to explore, and revitalize our own enthusiasm. I will never forget the first time I listened to Harold Dodge talk about continuous sampling. The places where we might use it, the sampling problems we might help solve by substituting it for plans we had in operation, and the savings we might be able to make, kept me enthused for weeks. Or the time I first heard about Vendor Certification. The idea appealed to me immediately as a long sought goal, and I could not wait to try it with some of our vendors. I am still a little amazed at the receptiveness of our vendors toward this philosophy.

We made some real savings through the use of Pre-control, a system of narrowed limit sampling developed by Mr. Dorian Shainin.

The possibilities of applying "overlapping tolerances" intrigued us some time ago and several members of our engineering staff accompanied me to visit some plants where they had made application of this technique. The contact was made through fellow members of ASQC and helped us launch a program that has since become quite successful.

These are just a few instances of many where through our associations in the Society we were able to profit by the experience of others. This opportunity is open to all quality control engineers for the asking.

In recent years there has been developing a quality control movement in foreign countries, and the Society has taken steps to establish through its Committee on Relations with other Societies, a contact with groups in other countries. Some of the outstanding leaders in the field of applied statistics are to be found in England, Germany and other foreign countries and it is most important that their work become better known in this country. There is little doubt that we shall as individual members of the Society, ultimately profit by a growing interchange of information with foreign quality control organizations.

The technological developments taking place in the field of quality control is paralleled by similar development in all branches of science and engineering, and impact of these ever increasing changes on our Society is tremendous. The problems arising from these changes give rise to a need for interpretation to society as a whole.

If we are to live in a peaceful world and make continued progress toward a fuller and more fruitful life, it is important that the scientists and engineers, who are bringing these developments into being, take a firm hand in guiding those charged with administration in government and industry, and help to educate the public not only to accept change but to relate it to our way of life, and our democratic philosophy.

Organizations of engineers and scientists are best able to present a unity of philosophy and rational thinking that will help clear away the skepticism, confusion and deep seated fears that build up in the average man as he sees the world around him rushing toward its own destruction.

There is a great need for disinterested public service on our part as a Society, and through joint efforts with such organizations as the Engineers Council for Professional Development, the Engineers Joint Council and others to assist in education of the public to guide the thinking of people to a better oriented point of view and more enlightened philosophy.

In conclusion, let me refer to my opening quote.

It is inconceivable to me that a quality control engineer today, with developments coming as rapidly as they obviously are, can hope to develop his "experimental knowledge", or develop "large experience" or become familiar with "practice in his profession" without the services offered by ASQC, namely active participation in its conventions, conferences, clinics, and section meetings and intensive study of its journal and technical literature.

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A DISCUSSION OF SAMPLING INSPECTION PLANS

H. F. Dodge
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This discussion considers the basic principles and special features of some of the systems of sampling inspection plans, both attributes and variables, that are available to the industrial quality engineer.

Among the various attributes inspection plans discussed are lot-by-lot acceptance systems, such as those covered by the Dodge-Romig sampling tables and MIL-STD-105A, continuous sampling plans, and certain so-called "small-sample" plans. The advantages and limitations of certain variables sampling inspection plans are touched upon, and the usefulness of "mixed" plans, using both variables and attributes, is noted.

The discussion brings out that the choice of sampling plan depends on the purpose of inspection, whether the material inspected is an isolated lot or one of a series, the available information regarding the quality history of product from the source under consideration, and considerations of economy and ease of administration.

CONTROLE DE LA QUALITE DES MOTEURS " 4 C.V. "

Paul Pommier
Régie Nationale Renault - France

1. Préambule - Lancée en fabrication en 1947, à la cadence de 300 par jour, la " 4 C.V. " a, depuis Mars 1956 une soeur de 5 C.V. : " La Dauphine", toutes deux sortent actuellement à la cadence journalière de 850.

Le moteur " 4 C.V. " est un 4 cylindres du type culbuté avec culasse aluminium ; c'est un moteur chemisé, à refroidissement par eau. Sa cylindrée est de 750 cm3 ; il développe au banc d'essais 22 C.V. à 3.500 t/minute et pèse tout habillé 82 Kg.

Du fait que sur la route ce moteur est utilisé presque toujours à puissance maxi, du fait que pour cette puissance il tourne, suivant les conducteurs, entre 4.000 et 4.500 t/minute, les exigences du Bureau d'Etudes sont très strictes, qu'il s'agisse des caractéristiques mécaniques des pièces traitées, de leurs dimensions, formes, états de surface.

Les jeux de fonctionnement très réduits, ont conduit le Bureau d'Etudes au choix de tolérances serrées, lesquelles jointes aux faibles dimensions des pièces (conséquence du faible poids du moteur) donnent des tolérances d'usinage de faible amplitude.

Quelques exemples ci-dessous :

En mm. et $\frac{1}{1000}$ mm.

- trou d'axe du piston : $\phi = 14$ $^{+\ 0,002}_{-\ 0,008}$
- trou d'axe du pied de bielle : $\phi = 14$ $^{-\ 0}_{-\ 0,008}$
- maneton du vilebrequin : $\phi = 35$ $^{-\ 0,025}_{-\ 0,041}$
- carter-cylindre, alésage ligne : $\phi = 44$ $^{+\ 0,000}_{+\ 0,011}$

Voulant procèder le moins souvent possible à l'appariement des pièces élémentaires des assemblages, solution chère et compliquée, nous nous sommes efforcés d'obtenir, à l'usinage, les cotes qui nous étaient demandées. De la sorte, nous avons connu quelques difficultés à la mise en route de cette fabrication en 1947, à savoir : pourcentages trop élevés, à notre grè, de loupés et de non-conformes qui résultaient du faible écart entre la dispersion de la machine équipée (intervalle entre 6 écarts types + % défauts de forme) et la tolérance, celle-ci étant pour nos ajustages précis souvent égale à la dispersion de la machine équipée.

Les machines étant en place, comment pouvions-nous améliorer la qualité produite devant l'état de faits suivants :

- la tolérance doit être respectée,
- la dispersion est ce qu'elle est, on la subit.

La machine équipée étant la meilleure à disposition sur le marché, il fallait dans nos ateliers d'usinage, nous efforcer de superposer au mieux la

valeur moyenne des cotes dispersées et la valeur moyenne de la tolérance, et pour ce faire :

- utiliser des appareils de mesure, de règlage, d'auto-calibrage précis au $\frac{1}{1.000}$ mm près,

— c'est le moyen d'action.

($\frac{1}{1.000}$ inch est 25 fois plus grand qu'un $\frac{1}{1.000}$ mm.)

- utiliser des cartes de contrôle,

— c'est le moyen de détection.

Cet historique du sujet à traiter, dans lequel nous n'avons parlé que d'usinage de pièces, ne représente qu'une partie du problème " Qualité des moteurs " 4 C.V." que nous allons envisager maintenant sur un plan plus général.

Toute manifestation d'activité est flanquée d'un contrôle ; un département de fabrication de moteurs, ses divers ateliers, voire même ses annexes, n'échappent pas à cet état de choses.

Encore faut-il bien définir les responsabilités, les prérogatives, de deux Directions importantes d'une grande usine comme la REGIE NATIONALE RENAULT (groupant à BILLANCOURT 35.000 travailleurs, et dans son ensemble 54.000) :

- la Direction des Fabrications,

- la Direction du Contrôle.

Rattachées chacune à la Direction Générale, absolument indépendantes l'une de l'autre, en fait, dans les diverses activités quotidiennes de la production, leurs actions se coordonnent, s'interpénètrent, se complètent au plus grand profit de l'Entreprise.

Nous allons étudier la répartition des tâches de ces deux Services importants, en nous appuyant sur les deux principes suivants qui ont guidé notre action de recherche de la qualité des moteurs " 4 C.V. ".

2. LA QUALITE NE SE CONTROLE PAS, ELLE SE FABRIQUE :

a) Tous les moyens mis par les Méthodes, le Contrôle et l'Atelier, à la disposition des productifs, doivent être capables de la production et de la mesure de la qualité prévue au dessin, ou, inversement, toutes les exigences des Etudes peuvent être satisfaites par les moyens mis en oeuvre. L'usinage constitue de la sorte une phase normale de la fabrication, dépourvue d'acrobaties, de tours de main, de retouches inadmissibles dans les productions de grande série.

Cela est loin d'être une évidence, mais j'estime indispensable d'y insister fortement étant donné, comme je l'ai dit précédemment, les tolérances ser-

rées que nous devons respecter et les faibles dimensions de nos pièces.

b) La condition précédente étant remplie, la responsabilité totale de la qualité incombe à la fabrication. Celui qui produit ne doit pas penser que le contrôleur rétablira derrière lui, par élimination de pièces douteuses, le niveau de qualité. Il doit obligatoirement pratiquer les opérations de vérification et d'essai nécessaires, il doit de lui-même :

- éliminer ses rebuts à l'opération,

- mettre de côté les non-conformes pour lesquels l'aide du contrôle lui sera nécessaire, par la suite, pour la destination à donner, à savoir, montage ou ferraille.

c) Le contrôle doit s'intégrer à la production sur la machine, car là est la source de la qualité, là se situe la possibilité d'action préventive que nous recherchons parce qu'elle est bien préférable à toute action corrective ultérieure.

Le contrôle en fin de chaîne ne doit être qu'une mesure de vigilance, qu'un gardiennage de la constance de la qualité au niveau voulu.

3. LE CONTROLE EST LE REPRESENTANT DU CLIENT AU SEIN DE L'ENTREPRISE.

La bonne réputation d'un véhicule est faite :

- par sa convenance aux désirs de la clientèle : ligne, habitabilité, aspect, performance, coût d'exploitation, etc....

- par le bien qu'en disent la grande majorité de ceux qui le possèdent.

Je dis bien " la grande majorité ", ce qui implique une qualité de véhicules peu dispersée, qualité toujours susceptible d'être améliorée, bien entendu, mais ne risquant pas, par sa dispersion, de faire d'un même client objectif et fidèle à la marque, une fois un satisfait la fois suivante un mécontent.

Donc, le client se fiant à la réputation définie ci-dessus, du véhicule, ne doit pas être déçu.

La constance de qualité (l'inconstance ne pouvant se manifester que vers le mieux) doit exister, et c'est le contrôle qui doit, au sein de l'Entreprise, en être le gardien vigilant.

4. COMMENT FABRIQUER LA QUALITE - COMMENT CONTROLER LA QUALITE - COMMENT AMELIORER LA QUALITE.

Dans notre département de fabrication des moteurs " 4 C.V.", les phases suivantes de travail se présentent pour lesquelles nous indiquons ci-dessous les méthodes de vérification que nous appliquons.

Usinage des pièces du moteur	a) sur machines : contrôle individuel - cartes de contrôle. b) en fin de chaîne : contrôle statistique par prélèvements sur lots ou sur flot continu - Indice de qualité par numéro de pièce.
Traitement thermique en cours d'usinage	a) sur matériel de traitement : Mise sous contrôle du matériel et de son entretien : débits et pressions de gaz, températures du four, des milieux de trempe, état des montages de traitement, etc..... b) sur pièces traitées : Vérification par prélèvements ou à 100 % des caractéristiques mécaniques et géométriques. c) Indice de qualité du matériel considéré.
Affûtage	a) Par familles d'outils : contrôle statistique par prélèvements de toutes les caractéristiques géométriques : forme, surfaces, etc..... b) Indice de qualité par atelier d'affûtage. c) Etude en chaîne d'usinage des problèmes posés par les outils coupants.
Montage des moteurs	Contrôle statistique sur la chaîne de montage, par prélèvements de toutes les opérations, par exemple : serrage des vis de culasses, règlage du jeu des culbuteurs, règlage de l'avance à l'allumage, etc.....
Essais des moteurs	a) Examen à 100 % des moteurs, tournant à vide par leurs propres moyens. b) Examen des caractéristiques essentielles sur moteurs prélevés : puissance, consommations : huiles et essence, frottements internes, reprises, etc..... c) Indice de qualité dont nous parlerons plus loin.

Le tableau ci-dessus confirme ce que nous avons dit précédemment, à savoir : l'interpénétration obligatoire des deux Services, Fabrication et Contrôle.

Il nous est donc difficile de les séparer dans l'examen que nous allons faire de leurs activités.

4.1. Créer le climat " Qualité ".

La qualité est un état d'esprit , un climat qui doit règner dans les ateliers de production ; elle exige de tous, le dynamisme, elle résulte de l'émulation, de la compétition, vers l'obtention du mieux.

Du Chef le plus haut placé dans la hiérarchie de l'Entreprise, jusqu'à l'ouvrier productif, chacun doit vivre intensément dans ce climat, à la fois par honnêteté vis-à-vis du client qui a des droits sur son fournisseur et vis à-vis de son Entreprise dont la bonne gestion est fonction de la réduction des gaspillages constitués, en majeure partie, par les loupés, les retouches et les arrêts de chaîne qui peuvent en être la conséquence.

Ce climat résulte : d'une organisation, de conférences, de cours, et de la divulgation de documents, toutes choses que nous avons mises en application.

Le Chef du Département de Fabrication des moteurs est assisté d'un " Ingénieur Qualité ", issu d'une grande Ecole française, initié à toutes les techniques de la statistique et de la recherche opérationnelle.

Cet Ingénieur est chargé :

- de la recherche des causes des défauts suivants : tolérances de dimensions, de forme, d'état de surface, non tenues ; anomalies constatées après traitement thermique : dureté, structure, forme,

- du maintien en état de qualité des moyens de production : réception des machines et de tout leur équipement de mesure et de règlage, visites des chaînes d'usinage, etc... etc....

- de la mise en évidence du coût des retouches, loupés, des dépenses de contrôle,

- de la formation, de l'information, par conférences, notes, causeries, instructions, de tout le personnel de maîtrise du Groupe, sur le sujet : Qualité,

- de la liaison avec les Services du Contrôle, le Bureau d'Etudes, le Bureau des Méthodes, Etc.....etc.....

Véritable aide de la Maîtrise de fabrication, dont il comprend et étudie les difficultés, et du Contrôle où il trouve ses parallèles formés à l'Ecole dans les mêmes disciplines intellectuelles, cet Ingénieur a contribué et contribue encore à créer le climat " Qualité " que nous désirons.

Il ne faut pas s'étonner si des années sont nécessaires pour créer ce climat, cette ambiance d'émulation, de compétition vers le mieux, car, comme dans toute compétition, on rencontre ici des indolents, avares de leurs efforts, et là, des sceptiques se soumettant trop docilement, à notre grè, à la fatalité des non-conformes et des loupés.

4.2. Fabriquer la qualité sur les machines, matériel, chaînes de montage, avec l'aide des cartes de contrôle.

En fabrication, l'usineur et le monteur sont les vrais responsables de la qualité des produits ; les machines et outillages, les ouvriers qui les commandent, les règleurs qui règlent le matériel, les matières ou pièces brutes mises en oeuvre, les divers ingrédients accessoires de la fabrication, les outils utilisés, les tolérances imposées, en un mot tous ces facteurs ne doivent présenter entre eux aucune incompatibilité. De la sorte, on a, à priori, la presque absolue certitude, sauf accident ou incident que tout ce que l'on fabrique sera bon, donc, répondra au niveau de qualité voulu.

Cela est indispensable dans la grande série en raison des perturbations qu'apportent dans la progression normale des pièces sur les lignes de fabrication, les loupés, les retouches, les règlages nombreux.

4.2.1. Mesurer la dispersion des machines dans leurs conditions de fonctionnement.

Toutes les machines que nous mettons ou remettons en service sont

réceptionnées du point de vue qualitatif par " l'Ingénieur Qualité " du département, qui détermine pour chaque opération la ou les dispersions, les compare aux tolérances et déclenche l'action nécessaire auprès des Services responsables en vue d'améliorer ce qui ne convient pas.

La Technique actuelle est telle que de plus en plus l'obtention de la cote désirée est demandée à la machine ; cette dernière a déjà par elle-même, et du fait de tout son équipement, suffisamment de facteurs de dispersion, pour que l'on essaie, chaque fois que cela est possible, de supprimer le facteur " intervention manuelle " de l'ouvrier et l'interprétation par ce dernier des résultats, en les remplaçant par un asservissement de la machine à une prise de cote en marche, voire même à un tri, à un classement automatique par dimensions. De plus en plus, nous faisons confiance aux machines à autocalibrage qui matérialisent pleinement la fabrication de la qualité.

En donnant l'automaticité complète à la machine, on y gagne :

- en précision,
- en rapidité d'exécution,
- On améliore les conditions de travail de l'ouvrier en réduisant ses efforts d'attention et sa fatigue ; il vérifie et ne laisse filer que ce qui est bon.

Quelques photos ci-dessous montrent, bien que trop imparfaitement, certaines de nos réalisations d'automaticité, dans la prise de cote et dans l'arrêt des machines :

Figure 1 : Machine " Micromatic " à pierrer les chemises, avec dispositif d'asservissement pneumatique et électronique.

Figure 2 : Machine à rectifier un arbre de boîte de vitesses, avec dispositif d'asservissement électronique.

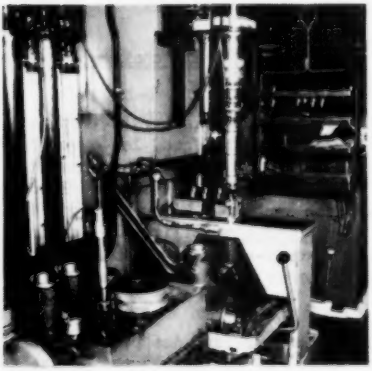


Figure 1

Figure 2

4.2.2. Mettre en application le contrôle individuel.

Il convient d'inculquer à l'ouvrier qui effectue une opération, soit d'usinage, soit de montage, la nécessité de contrôler en permanence, le travail suivant le plan prévu pour l'opération, c'est-à-dire à 100 % ou par prélèvement.

Cette obligation de contrôle individuel nécessite donc la mise en place, sur les machines ou à proximité, à chaque opération, d'un appareillage de mesures précis, et en particulier dans le cas des tolérances d'ordre 5 - 6 - 7 et 8 que l'on rencontre fréquemment sur les pièces d'automobiles.

On a recours, pour ces tolérances, à l'emploi de micro-mesureurs, soit pneumatiques, soit électriques, soit électroniques, dont on trouve d'ailleurs des types très variés et très ingénieux dans l'Industrie française de la Mécanique de haute précision. Parallèlement à l'équipement des machines en appareils de mesures, est réalisé l'équipement en appareils de règlage d'outils, la précision de ce règlage devant être du même ordre que celle de la mesure.

Figure 3 : Appareils de vérification et de mesure des alésages de la boîte de vitesses " 4 C.V. ".

Figure 4 : Appareils de règlage des grains sur barre d'alésage de carter-cylindres 4 C.V.

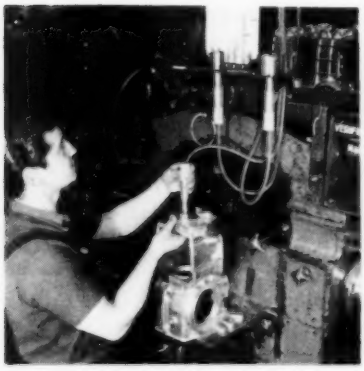


Figure 3

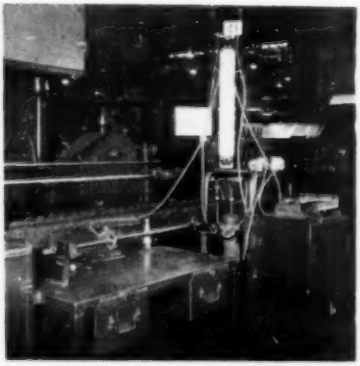


Figure 4

Ainsi, nous demandons de plus à l'ouvrier productif chargé déjà de mesurer sur la machine, les pièces, suivant le plan prévu :

- de laisser suivre leur progression, dans la chaîne, aux pièces bonnes,
- de mettre de côté, en les séparant, loupés et non-conformes qui seront soumis obligatoirement au contrôle qui fixera leur destination,
- d'arrêter la machine et d'appeler le règleur dès qu'il constate des loupés ou des non-conformes, soit consécutifs, soit à un intervalle très rapproché, car mieux vaut ne rien produire que produire des pièces présentant des anomalies.

Ce contrôle individuel, ce self-control, est la base de tout notre programme " Qualité ".

En effet, la garantie de qualité est donnée dans une chaîne (usinage ou montage) par un nombre indispensable d'opérations de contrôle prévues par un plan qui en définit le responsable qui est soit l'ouvrier, soit le règleur, soit le contrôleur, mais il ne doit pas y avoir double emploi, sinon le coût de la fabrication en serait affecté.

Les opérations de vérification représentent une constante ; si l'évolution de la qualité dénote un relâchement de la part de l'usineur, les contrôleurs doivent renforcer leur action en aval, et inversement.

Le contrôle est une assurance contractée pour garantir la qualité ; mettons tout en oeuvre, lors de l'étude des plans, pour que le coût du contrôle représentant le montant de cette " assurance qualité " soit minimum pour une garantie maximum.

Le règleur à qui incombe d'ailleurs plus qu'à l'ouvrier, la responsabilité de la qualité, n'est pas dispensé de quelques super-contrôles.

4.2.3. Mettre en utilisation, dans les chaînes, les cartes de contrôle.

- Cartes aux mesures : qui permettent, pour les tolérances serrées, comme nous l'avons dit précédemment, de réduire au minimum, loupés et non - conformes, en superposant par le règlage, la valeur moyenne des cotes dispersées et la cote moyenne donnée par la tolérance, et qui permettent, en outre, de suivre l'évolution du " range ".

- Cartes aux pourcentages : qui permettent, suivant l'évolution des pourcentages de défauts, d'apporter les corrections nécessaires, soit au règlage, soit à la qualité de la machine.

4.3. Contrôler la qualité finale suivant un plan de contrôle.

Par " qualité finale " nous sous-entendons la qualité à l'achèvement d'une des diverses phases de fabrication dont nous avons parlé précédemment, c'est-à-dire :

- en fin de chaînes d'usinage des pièces,
- en fin d'affûtage des outils,
- en fin de montage des moteurs,
- etc....etc....

Si, au cours de la fabrication, tout répondait aux désirs du Bureau d'Etudes, on pourrait se passer du Contrôle. Mais dans l'état actuel de la technique de production, et compte tenu des exigences de qualité, cela semble impossible ; d'autre part, malgré toutes les consignes données, le contrôle individuel n'est pas toujours appliqué par l'ouvrier productif et le règleur avec toute l'efficacité souhaitée ; c'est donc pour pallier certaines imperfections, certaines faiblesses humaines, certaines auto-indulgences, que le contrôle indépendant, doit prendre une part de responsabilités dans l'obtention de la " qualité ".

Le Contrôle doit :

- Contrôler pour maintenir le niveau de qualité voulu.
- En tirer tous les renseignements possibles en vue d'améliorations.

- Apporter, si nécessaire, son aide à la fabrication pour obtenir des Méthodes, un matériel mieux adapté aux exigences de qualité ou pour obtenir des Etudes, moins d'exigences à l'usinage ou au montage sans pour cela altérer la qualité de l'organe monté.

- Informer la Direction sur le niveau de qualité obtenu.

- Assurer toutes ces tâches au moindre coût.

En général tous ces " contrôles finals " sont opérés par prélèvements soit sur lots, soit sur flot continu.

Chaque jour, sont reportés par le Contrôle, sur un tableau installé en fin de chaîne et bien en vue de tous : les pourcentages de loupés, de non - conformes.

Figure 5 : Ensemble du poste de contrôle des vilebrequins " 4 C.V. "

Figure 6 : Etat journalier des non-conformes et des loupés.

Figure 5

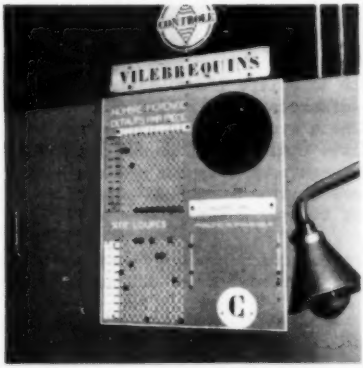


Figure 6

Deux fois par mois, a lieu dans le bureau du Chef de Département "Moteurs" une conférence " Qualité ". Toutes les opérations donnant des productions douteuses sont examinées, et, si je puis m'exprimer ainsi, c'est le Chef du Contrôle qui conduit l'accusation.

Il en résulte :

- des décisions,
- des désignations de responsables,
- des fixations de délais.

Nous signalons pour mémoire, que, par ailleurs, le Contrôle a établi et utilise des plans de réception pour tout ce qui vient de l'extérieur : joints divers, dynamos, démarreurs, pompes à essence, allumeurs, etc....etc.....

La chaîne de montage, les essais et contrôles au banc, sont les derniers obstacles à l'utilisation des pièces douteuses.

- Certaines pièces non conformes, certains sous-organes, ont pu franchir le contrôle sans être arrêtés, qu'ils proviennent :

  - soit de nos ateliers,
  - soit de fournisseurs extérieurs.

- Certaines pièces à la limite des tolérances, peuvent donner des assemblages inacceptables, soit par excès de jeu, soit par excès de serrage, soit par leur bruit.

- Sur la chaîne de montage, certains règlages : jeu des culbuteurs, serrage de vis, règlage de l'avance à l'allumage, peuvent être hors des limites.

- Certaines performances : puissance, consommation d'essence, consommation d'huile, peuvent être inacceptables.

- la peinture peut manquer de soin, etc...., etc.....

Il résulte de tous ces facteurs que certains moteurs ne sont pas livrables à la clientèle, et que certains de ceux qui lui sont livrés, peuvent ne pas avoir la vraie qualité que nous désirons.

Afin de suivre l'évolution vers le mieux, de cette qualité, nous nous sommes efforcés de faire de cette dernière une grandeur mesurable ; plus exactement nous avons cherché à mesurer les malfaçons en fonction de leur coût, la qualité étant bien à ce dernier stade de la fabrication une question de coût puisque pour tous les défauts mentionnés ci-dessus il est possible par retouches de transformer un moteur non accepté par le contrôle en un moteur livrable à la clientèle.

En conséquence nous communiquons périodiquement à tous ceux qui concourent à la fabrication des moteurs :

  - nos fournisseurs,
  - notre maîtrise d'atelier,
  - le Bureau d'Etudes,
  - notre Direction,

- un Indice de qualité de nos moteurs,

- le supplément de coût par moteur pour obtenir la qualité voulue.

Indice de qualité.- Il s'agit d'un indice moyen sur deux semaines de production. Si toutes les caractéristiques des moteurs étaient satisfaisantes pour le contrôle, l'indice moyen serait 20.

Par contre, toute retouche nécessaire pour donner un organe livrable à la clientèle, entraîne une minoration de note (demerit). la note finale obtenue après toutes minorations donne " l'Indice de qualité " dont les variations dans le temps nous intéressent davantage que la valeur obtenue qui est conventionnelle.

- Nous avons dressé la liste de tous les défauts que par expérience nous avons rencontrés et qui donnent lieu à retouches.

- Chaque défaut a été affecté d'une valeur de base qui est la minoration à appliquer lorsqu'un moteur sur 100 présente le défaut.

- Le produit de la valeur de base par le pourcentage de moteurs défectueux, donne, pour un défaut, la minoration de note qu'il entraîne.

Nota : Les valeurs de base ont été établies proportionnellement au coût de la retouche du défaut considéré ; un même défaut peut se découvrir à différentes phases de la fabrication du véhicule ; la minoration qu'il entraîne est d'autant plus élevée que l'on approche de l'achèvement de la voiture.

Coût de la qualité, dû aux malfaçons.-

Si l'indice de qualité est une expression conventionnelle de valeur seulement relative dans le temps, par contre, le coût est une réalité.

C'est la somme, par moteur sorti bon, de tous les dépassements de dépenses ou de toutes les dépenses anormales, aux divers stades de fabrication de la qualité, c'est-à-dire :

- à l'usinage : - coût des loupés d'usinage ou de mauvaise matière.
  - coût des retouches de pièces non conformes et des pertes de production qui en résultent.
- au traitement thermique : coût des loupés et retouches.
- au montage : coût des retouches, valeur des pièces qui ne se montent pas.
- en salle d'essai : coût des retouches de défauts avec échange de pièces ou de sous-organes.
- en cours de montage des véhicules : coût des retouches et retours de moteurs au département de fabrication.
- en clientèle : coût de la garantie, sans oublier ce qui n'est pas chiffrable : mécontentement de la clientèle et mauvaise publicité pour le fabricant.
- en plus de cela, coût du Service Contrôle Moteurs : Main-d'oeuvre, appointements, charges sociales, etc.....

L'examen par tous ceux qui concourent à la fabrication des moteurs " 4 CV des deux critères ci-dessus, leur permet de faire leur auto-critique : en fonction de la chute de note de qualité dont ils sont responsables et en fonction du coût supplémentaire qui en résulte.

L'importance et l'urgence des améliorations à apporter sont ainsi définies.

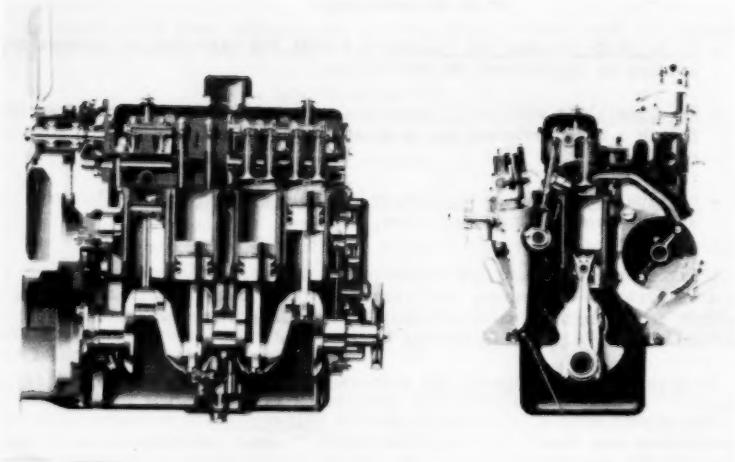
Nous pouvons mentionner les résultats suivants :

	1955		1956
	Janvier	Octobre	Janvier
Indices de qualité	15	15^5	16^5
Coût des malfaçons par moteur	890 fr	773 fr	710 fr

En conclusion, ne peut-on pas se poser la question suivante : Ce souci constant à la Régie Renault, d'amélioration de la qualité, n'est-il pas une cause particulière du grand succès, auprès de la clientèle de tous les pays du monde, de la " 4 C.V. " et de sa jeune soeur, la " 5 C.V. " ?

P. Pommier

Le Moteur " 4 C.V. "



THE QUALITY CONTROL IN THE MANUFACTURE OF THE " 4 C.V. " RENAULT ENGINES

Paul Pommier
Régie Nationale Renault - France

1. History.-

Set in fabrication in 1947, at the output rate of 300 units per day, the " 4 C.V. " car, since March of this year, has now got a " 5 C.V. " sister car, the so-called " Dauphine ", the total production rate of the two models being of 850 units per day.

The " 4 C.V. " engine is a 4 - cylinder one with rocker-arm, o.h. operated valves and aluminium cylinder head ; its cylinders are of the lined, water-cooled type. With a displacement of 45.8 cu. in., it develops 21.7 bhp at 3.500 rpm, and, including all equipments, weighs 181 lbs.

Owing to the fact that this engine is nearly always used at its maximum output on high roads and, in these conditions, will rotate at 4.000 - 4.500 rpm, depending upon whom it is driven by, very stiff requirements are imposed by the RNUR's Engineering Department, whatever may be the point in question : mechanical characteristics, dimensions, shapes or surface conditions of the processed parts.

Owing to the very low working clearances allowable, the Engineering Department has been led to choose close tolerance Standard Classes, which, combined with the small dimensions of the parts (as a consequence of the light engine), entail close machining tolerances, as illustrated by the following figures :

- gudgeon-pin piston bore I.D.	14	+ 0,002 mm - 0,008 mm
- connecting rod small end bore I.D.	14	- 0,000 mm - 0,008 mm
- crankpin O.D.	35	- 0,025 mm - 0,041 mm
- cylinder-block bearing bore I.D.	44	+ 0,000 mm + 0,011 mm

As we want to have, as rarely as possible, to match the assembly unit components the ones with the others, a costly and intricate operation, we have endeavoured to obtain the required dimensions at the machining stage. It meant for us some troubles, i.e. too high percentages, in our opinion, of scraps and defective parts, during the early period of production of these engines, in 1947. By defective parts we mean reclaimable parts as well as scrap or waste and by non conform parts we mean off-tolerance parts that may or may not be assembled without rework depending upon the controller's decision.

Such high percentages of reject originated from the small difference of value between the scatter (the interval between 6 standard deviations, increased of a certain percentage of shape defects) of the manned-and-equipped machine-tool and the tolerance, the two values being often equal due to our accurate adjustments.

With the machine-tools available, how could we improve the level quality with the following conditions :

- the tolerance values had to be kept,
- the natural deviation is a fact and so could not be modified.

Although our machines were the best available on the market, their natural deviation were such as they could hardly keep the tolerances. Then we were obliged to set tools with a high precision, not to lose any smaller part of our tolerances, for this purpose :

a) to use measuring, fitting and self-gaging apparatus with a precision of 0,001 mm (which is 4 hundredths of one thousandth of an inch),

- this is the operating means ;

b) to use " X cards " to control the mean,

- this is the detection process.

In the above history of our subject-matter, we have so far discussed only the question of machining engine parts, which is but one particular aspect of the problem of the quality of the 4 C.V. Engines, which we shall now consider on a more general way.

Inspection process is always associated to any activity, an engine production department with its diverse shops and even its annexes, does not escape this rule.

However, to begin with, it is necessary to define clearly the responsibilities and rights of the two following important managements of such a big concern as the REGIE NATIONALE RENAULT (they employ 35.000 men at Billancourt and 54.000 men as a whole) :

- the Production Management,
- the Control and Inspection Management.

Both these managements are attached to the General Management and absolutely independant from each other, but actually, in their various daily productive activities, they cooperate, interlace, and complete each other to the best of the concern.

Further on, we shall discuss how these two important department' duties are distributed, on the basis of the two principles hereafter, whose guidance we have used in our efforts to boost the quality of the " 4 C.V. " engines.

2. <u>QUALITY is not made by inspection but by operators and machine-tools</u>.

a) All the means that are given to the workmen disposal by the Methods Engineering Department, Control and Inspection Department, should allow the workmen to produce work of the required quality and measure them easily or, conversely, all the Engineering Department's requirements should be met by the tools used in lines. Thus, machining is a normal stage of the fabrication , free from acrobatics, know-how and reworks inacceptable with mass production.

I feel indispensable to insist strongly upon this point of view because of the close tolerances to be met and the small dimensions of our parts, as mentioned above.

b) Assuming that the latter condition is satisfied, the total responsibility of work quality rests with the productive labor. The one that produces should not rely upon the inspector to restore the quality level behind him, through elimination of the defective parts. Rather, he ought to perform the necessary checking and testing operations, and spontaneously :

- reject his defective work on the job,
- put aside the defective parts, for which he will ultimately need assistance from the Control and Inspection Department to know whether they belong to the reclaimable or scrap category.

c) The control operations should be embodied in the machine - tool production, for it is at this stage that lies the source of quality and the possibility of taking preventive steps, which we do prefer to any ulterior corrective steps.

End-of-line inspection should be but a safety measure, to ensure that quality is maintained at the required level.

3. The Control and Inspection Department is the customers' representative inside the concern.

The good repute of any vehicle results from :

- its adequacy to the customers' requirements, i.e. styling, roomability, aspect, performances, running cost,.....
- what he thought of it by the great majority of its owners.

I insist upon the expression " the great majority ", which means a vehicle quality of narrow range, always apt to be improved, and for all that not likely to fluctuate to such a degree as to make alternately a satisfied and discontented man of the same objective, sticking-to-one-make customer. He that relies upon the manufacturer's repute as above defined must not be disappointed.

The steadiness of quality must be (the non steadiness being allowed to appear only on improvement) and, inside the concern, it is the Control and Inspection Department who keeps it.

4. How to " make ", control and improve quality ?

In our " 4 C.V. " Engine Production Department, the work goes through several operations, to which we apply the following control methods, respectively :

Machining the engine components

a) machine-tools : individual control with quality control cards.

b) at the end of production line : statistical quality control by sampling after either the lot-plot or the continuous-flow method, with one quality index for each part.

	(The continuous-flow method of sampling consists in sampling parts from the production flow at a variable rate depending on the quality level).
Heat treatment on work in progress	a) <u>treatment equipment</u> : controlling the equipment and its proper maintenance as regards gas output and pressure, oven temperature, quenching medium, condition of fixtures,.....
	b) <u>treated parts</u> : checking the mechanical and dimensional characteristics after either the sampling or part-by-part method.
	c) computing a quality index of used equipment.
Tool grinding	a) <u>on tool group</u> : statistical control of tool geometry - dimensions, shape, surface condition,.....
	b) quality index for each tool grinding shop.
	c) analyzing the problems concerning cutting tools in the machining line.
Assembling the engines	applying statistical control to all the operations, e.g. tightening the cylinder head bolts, setting the clearance of rocker-arms, adjusting the ignition timing, ...
Testing the engines	a) individual checking of the engines at idle running.
	b) checking the main characteristics of sampled engines i.e. power output, oil and gasoline consumption, internal frictions, power pick-up,.....
	c) computing a quality index as explained later in this report.

The above list confirms what we have already stated, that is the necessary for the Production Department's, Control and Inspection Department's activities to cooperate.

It is the reason why we are somehow obliged to handle these activities together, as follows :

4.1. <u>Setting up the " Quality " climate</u>.

Quality is a climate which should prevail in all the production shops ; it requires dynamism from everybody and results from emulation and competition towards improvement.

From the top executive in the hierarchic line down to the operators, everyone must be intensely " Quality-minded ", for loyalty both to purchasers, who have rights on their vendor, and to his own concern, whose good management depends on the reduction of waste, i.e. rejected parts, reworks, and the ensuing down-times in production lines.

This quality climate is fostered by a special program including discus-

sions, lectures, and disclosure of records, all of which we have put in application.

The Superintendant of the Engine Production Department is assisted by a " Quality Engineer ", who was graduated at one of the leading French engineering schools and trained in all the methods of statistics and operational research.

This Engineer is in charge of the following duties :

- Investigating the causes of the productive labor's inability to keep the dimensions, shape, or surface condition of the parts within the specified tolerances, and of the abnormalities found after the heat treatment, as regards the hardness, texture and shape of the parts ;

- keeping the production tool in a state of quality, checking the machine-tools and all their measuring and fitting equipments, inspecting the machining lines,.....

- setting forth the cost of reworks and defective parts as the control expenses ;

- training and informing the department foremen with lectures, notes, discussions and instructions, on the matter-subject of quality ;

- ensuring the liaison of the Production Department with the Control and Inspection Department, Engineering Department, Methods Engineering Department, ...

The very auxiliary of the production foremanship, whose difficulties he will analyze and relieve, and of the Control and Inspection Department, where he will contact his fellow-men, graduated in the same technical branches as his own ones, this Quality Engineer has contributed and is still contributing to create the " Quality " climate that we aim at.

No wonder if this climate, this ambiance of emulation and competition towards improvement, needs years to set up because of the condition inherent to any such enterprise, i.e. that some participants are floppy in character and toil-reckoning and other, sceptical ones are too prompt, in our opinion, to take non-conform and rejected parts as bound to occur.

4.2. "Making" quality through quality control cards in machine-tools, materials and assembly-lines.

As far as fabrication is concerned, it is upon the operators and setters up, and more generally upon all those in charge of the proper operation of the machine-tools, that lies the true responsibility of the quality level of the products ; all the machine-tools and tooling, the operators that run them, the fitters that set them, the raw materials and semi-products, the diverse indirect materials, the toolsand the specified tolerances should not be uncompatible. This will ensure a priori that, unless any unforeseen accident or trouble should occur, the whole production shall be reliably good, i.e. shall meet the required level of quality.

All this is indispensable in mass production because of the perturbances that are brought about by rejects, reworks and re-settings in the normal process of the parts through the machining lines.

4.2.1. Computing the " X standard deviation " of machine-tools in their operating conditions.

All the new and rebuilt machine-tools that we start are checked from the qualitative viewpoint by the Production Department's " Quality Engineer " who will determine the one or several " X standard deviation " values for each operation, compare it or them with the pertinent tolerance values and take the necessary steps in the responsible Services in order to improve what may be defective.

Modern technic is such that, to an ever increasing degree, the specified dimensions should be obtained from the machine-tools proper ; as these machines comprise a rather large number of scattering factors, both intrinsically and owing to their whole equipment, it is reasonable to try, wherever possible, to eliminate the operator's " hand " factor and evaluations of the results and substitute to them the slaving of the machine-tool to an " in - run ning " dimension recording device or even to an automatic dimensional sorting equipment. We rely to an ever increasing degree in auto-gaging machine-tools, which are fully representative of quality production equipment.

By getting the machine-tool entirely automatic, following advantages are gained :

- a better precision,
- a quicker operation,
- improved working conditions for the operator through reduced strain and fatigue ; he then has but to check the work, letting pass only what is good.

The few annexed photographs (Figure 1 and Figure 2) will, though rather scantily, show some of our achievements in automaticity as to dimensional recording and machine shutting off.

Figure 1 : " MICROMATIC " honing machine fitted with a pneumatic and electronic slaving device, for honing the cylinder liners.

Figure 2 : Grinding machine fitted with an electronic slaving device, for grinding gearbox shafts.

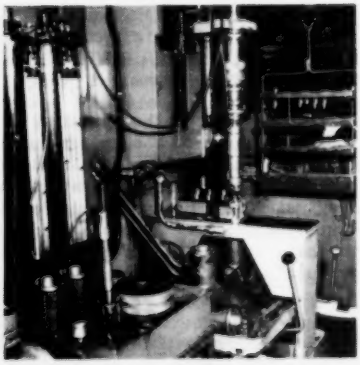


Figure 1

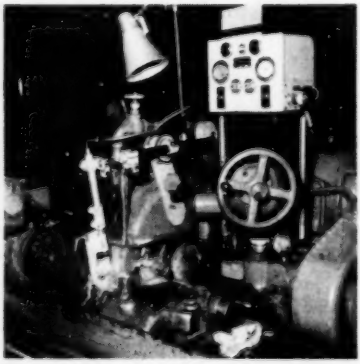


Figure 2

4.2.2. Applying the individual control scheme.

It is good practice for the man who will have to carry out either a machining or assembling operation to be forced upon the necessity of controlling the work permanently according to the method prescribed for this particular operation, i.e. either a part-by-part or sampling control.

This necessity of an individual control entails the setting up of precise measuring equipments incorporated to or close to the machines, in particular where tolerances of the Standard Classes 5 to 8 are required, as it is often the case for automotive parts.

To keep these tolerance values, we use micro-gages of the pneumatic, electrical, or electronical types, of which the French manufacturers of high precision instruments offer a large range of models. On the other hand, as the tool setting should be of the same order of precision as that of work dimensional measurement, our machine-tools are also equipped with high precision tool setting instruments (see Figure 3 and Figure 4).

Figure 3 : Checking and measuring apparatus used for the " 4 C.V. " gearbox bores.

Figure 4 : Apparatus for setting the cutting tips on the boring bars for boring the " 4 C.V. " cylinder-blocks.

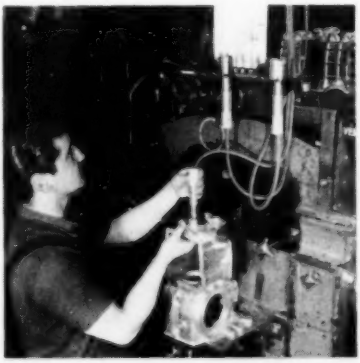


Figure 3

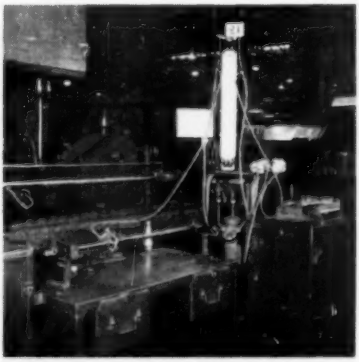


Figure 4

Thus, to the operator, who has already to measure the parts on his machine-tool, after the designed schedule, we ask also to perform the following operations :

- letting the good parts normally progress along the line ;
- putting aside and sorting the rejected and non-conform parts, which shall be subjected to the quality control and dispatched in the proper directions ;
- stopping the machine-tool and calling for the fitter as soon as he finds defective or non-conform parts, either consecutively or at a very high rate, for better to produce nothing than abnormal parts.

This individual control is the base that our whole " Quality " program

depends upon.

As a matter of fact, the guarantee of quality in any - machining or assembly - line is ensured by the performance of a set of indispensable control operations provided in a schedule, which specifies the responsible man. While the latter may be the operator or the fitter or the controller, there should not be overlapping responsibilities, otherwise the production cost would be altered.

The all round checking operations should have a constant right result : if quality trend reflects a slackening from the operators, the inspectors must reinforce their action downstream, and vice versa.

As the control system forms an insurance we have undersigned to guarantee the production quality, let us apply all possible means, at the designing stage, in order that the control cost, which represents the premium of the policy of this " quality insurance ", be as low as possible for a maximum guarantee.

The fitter, who is more responsible than the operator for the quality level, is not dispensed to overlook operations.

4.2.3. Putting the quality control cards in application in the machining lines.

We use the two following kinds of quality control cards :

- The $\bar{X}$ and $\bar{R}x$ control cards. As mentioned above, it is possible with them to minimize the number of defective and non-conform parts of close tolerances by fitting the machine-tool so that the average value of the scattered dimensions coincide with the average dimension resulting from the tolerance, and it is also possible to follow the variations of range.

- The " per-cent defective parts " cards. They indicate the direction of corrections to be brought, depending on the variations of the percentage of defects, either in the fitting or in the quality of the machine-tool.

4.3. Inspecting the end quality after an inspection schedule.

By " end quality " we mean the different levels of quality of work on completion of the process stages that we have mentioned above, i.e.

- at the delivery ends of the machining lines,
- at the final operation of tool grinding,
- at the delivery end of the assembly line,
- .....

Assuming that, throughout the fabrication, the characteristics of the engine parts met the Engineering Department's requirements, the quality inspection program could be discarded. However, in the present state of production engineering, and the required level of quality being allowed for, there seems to be no possibility of this kind. Further, in spite of all the instructions laid down, the individual control schedule is not always applied by the operators and fitters with the desired efficiency. It is to obviate human imperfections, feebleness and self-indulgence, that independant inspectors should share the overall responsibilities in the achievement of " quality ".

The Control and Inspection Department should fulfill the following duties

- inspecting the outgoing products to maintain the required quality level

- deriving the maximum information from this inspection for the benefit of improvements ;

- if necessary, backing the Production Department in their requests to the Methods Engineering Department for a material more adapted to quali ty requirements or to the Engineering Department for more tempered machining or assembly requirements without a deterioration of the quality of the assembled components ;

- informing the General Management on the level of quality achieved ;

- fulfilling all these duties at a minimum cost.

Generally, all these " outgoing " inspections are carried out through either lot-plot or continuous flow samplings.

Every day, the percentages of defective and non-conform parts are posted by the Control and Inspection Department on a board set up at the different line delivery ends, in full sight (see Figure 5 and Figure 6).

Figure 5 : Overall view of the Control Station of the " 4 C.V. " crankshafts.

Figure 6 : Daily report on the non-conform and defective parts.

Figure 5

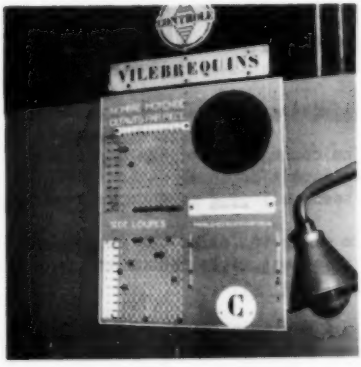


Figure 6

Twice a month, a " quality " discussion takes place in the Engine Department Superintendant's office. There, all the process operations that result in questionable products are scrutinized, the prosecutor, if I may say so, being the Control and Inspection Manager.

The issue of this discussion consists of the following items :

- decisions are taken,

- liabilities are determined,

- times allowed for correction are fixed.

Let us mention incidentally that, on the other hand, the Control and Inspection Department will set and use acceptance schedules for all the procured parts such as diverse seals and gaskets, generators, starters, gasoline pumps ignition-distributors,.....

The assembly line and the bench tests and checks form the ultimate barrier to the integration of questionable parts in the engines.

However, for the following reasons, the production quality may be impaired :

- Some non-conform parts or sub-assemblies,

  - either of our fabrication,
  - or procured by suppliers,

may have gone through the controls without being arrested.

- Some parts machined straight to the limits of tolerance may lead to inadmissible assemblies, because of an excessive looseness or, conversely, too tight a fit, or their being too noisy.

- In the assembly line, some adjustments, such as the rocker-arm clearances, screw tightening, and ignition timing, may be off the tolerance limits.

- Some performance test data of the engines, such as power output, petrol and oil consumption figures, may be inadmissible.

- Painting may have been carelessly carried out, and the like.

The consequence of the above factors is that some engines are not in the proper condition to be delivered to the customers and some other ones, which have been delivered to them, may not be of the <u>real quality</u> we aim at.

In order to follow the improvement of quality, we have endeavoured to make it a measurable factor and, more precisely, to measure defects in terms of <u>what they cost</u>.

As a matter of fact, quality is a question of cost at the ultimate stage of production, for the following reason : any engine that has not been accepted by the Control and Inspection Department for any of the above mentioned defects can be reworked into an engine that <u>can</u> be delivered to the customer.

Accordingly, we regularly inform all those who contribute to the engine fabrication, i.e.

- our suppliers,
- our foremen,
- our Engineering Department,
- our General Management,

of 1) the quality index of the engines,

2) the extra cost per engine necessary to achieve the required level of quality.

The Quality Index.- The quality index is worked out as an average on the basis of two production weeks. If all the engine characteristics were satisfactory to the Control and Inspection Department, the value of this average index would be 20.

On the other hand, any rework necessary to make a component delivery - worth results in a demerit to be deducted from the quotation of quality. The final quotation obtained through deducting all the demerits and averaging the quotations is the " Quality Index ", whose time variations are more valuable to us than the intrinsic value, which is arbitrary.

The following procedure is used to determine the demerits :

- We have listed all the defects that, from our experience, are liable to occur and entail rework operations.

- To each defect has been assigned a basic value, which represents the demerit to be applied to the quality index if the defect considered occurs in one per cent of the engines.

- Finally, the demerit relevant to a given defect computed by multiplying its basic value by the per-cent of engines presenting this defect.

N.B. - The basic values of defects have been prorated to the rework cost of the respective defects. A given defect may occur at different stages of the fabrication ; however, the nearer the fabrication stage to the car comple tion, the higher the demerit implied by this defect.

How much does quality cost, owing to defects ?

While the quality index is an arbitrary factor, whose time variations only are of value, the cost of quality is a sensible reality.

It is the total, per accepted engine, of all the following extra or abnormal expenses incurred at the different stages of " quality making " :

- machining
  - cost of rejected parts for either defective machining or material ;
  - cost of reworking non-conform parts and related production losses.
- heat treatment : cost of defective parts and reworking operations.
- engine assembling : cost of reworking operations and factory cost of parts unsuitable to assembly ;
- testing : cost of reworking defective parts and replacing components and sub-assemblies.
- car assembling : cost of reworking operations and sending back of defec tive engines to the Engine Production Department ;

- <u>at all production stages</u> : cost of the Engine Quality Control Section, i.e., labor, foremen and supervisors' salaries, social security allowances,.....

In top of the expenses listed above, account should be taken of the following items, which form penalties to lack of quality :

- <u>after-sale expenses</u> : cost of repairing and replacing unsatisfactory parts under guarantee,

- <u>intangible factors</u> such as unsatisfied purchasers and counter-publicity to the manufacturer.

By analyzing the control and inspection, as well as guarantee, costs, all those contributing to the fabrication of the " 4 C.V. " engines are enabled to autocriticize in terms of that fraction of the drop in quality index that they are liable for, and of the resulting extra cost.

On this basis, the importance and urgency of the improvements to be brought about can be defined.

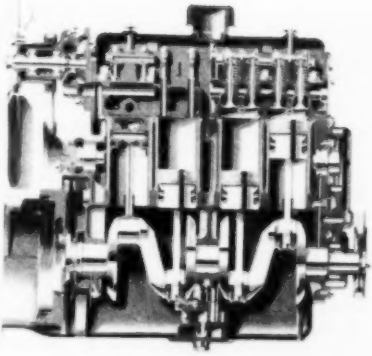
As an illustration of the success of our quality program, let us mention the following figures :

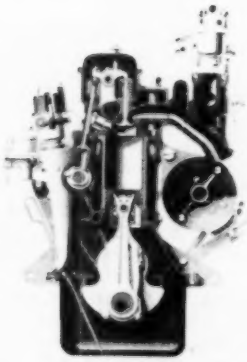
	1955		1956
	January	October	January
Quality Index.....	15,-	15,5	16,5
Cost of defects per engine (in Francs):	890	773	710

To conclude, the following question might not be irrelevant : May not this constant care to improve quality, which is a policy at the Régie Renault be a particular cause for the outstanding success, all over the world, of the " 4 C.V. " car and its " 5 C.V. " sister car, the " Dauphine ".

Paul Pommier.

The " 4 C.V. " engine.





ESTABLISHING STANDARDS IN THE PAPER INDUSTRY

Frederick G. Crane, Jr.
Crane & Company, Inc.

The term "standards" is a very broad term and I feel it essential to limit the word to some degree. I would like to limit this paper to discussing standards by which the mill or manufacturer gauges his product as to whether it is suitable to ship or not. It will include those within-mill specifications and standard samples and other techniques which are used by mill management rather than set by the customer himself.

This report is based on experience in a branch of the paper industry which concerns itself primarily with specialties; our form of standards is, therefore, somewhat different from those industries which are chiefly concerned with supplying a standard item to a general trade. In most cases, the relationship with a customer is one in which the customer will ask for a paper to be used in a certain operation and all he asks is that it perform satisfactorily in that operation. With that as a background, we try to develop a paper to suit their needs. This situation has been extant for a great many years and the result has been that in our organization, we have three or four men, each of whom is an expert at understanding the needs of a few customers. When questions of quality come up or when a lot of paper is produced which is marginal in quality, these are referred to this one man and his decisions are final. All complaints registered by the customer are also channelled through him. This method of setting standards has worked well for a good many years and it has certain definite advantages. The specialist for each group of customers has a very intimate knowledge of their requirements. He can quite closely evaluate how our product is going to operate in the customer's plant. He knows what faults will cause most of the trouble and what ones will get by unnoticed. If he has done his job well, the customer will have confidence in him and as customer requirements change, he will keep up to date with them.

This procedure works well in a small company with a limited number of products. However, this method is very consuming of man power when a company's products and customers are quite varied. For some time, the company has felt that this method of gauging quality is no longer satisfactory.

It has, therefore, become evident that what was needed was a full set of standards which could be written down and available to all interested and which would be the standards by which our quality was measured for each individual grade. It is imperative that such a record be kept properly up to date. This has been my problem for the last two years.

Before much can be done on setting standards in any industry, it would be well to get a clear understanding of what we mean by a standard. Webster's definition of a standard is as follows: "That which is set up by general consent as a model or example of quality which is proper and adequate for a given purpose, or as a rule for the measure of quality." This definition needs some further exploring. The phrase "general consent" means that it must be 1) agreeable to the manufacturer and the manufacturer agrees that he is able to produce this quality under normal conditions, and 2) that it is acceptable to the customer. Also, following the definition further, a standard can be either a written descrip-

tive model, or it can be actually a physical sample of quality, or it can be a rule or test for quality.

It is important when setting standards, that one choose the right spot on the normal curve of production to set as a standard of quality. Many times a standard is set which is understood to be the median or average quality produced. This is unsatisfactory because it then requires that a lower limit be set also, below which the product cannot be shipped. In setting any standard, it is advisable to set the standard at the lower limit of the normal production, be it 2 sigma or 3, or some other arbitrary point and that below this point, the product is substandard.

Another item to be given close examination before writing down a standard is the sample size when sampling is being done. This particularly is a problem in the paper industry where a small sheet of paper represents a ton or more of finished product. It is well to have some understanding of how well that sample is likely to be representative of the whole lot. This means investigating the variability of quality within the unit being sampled.

When standards are being set, it is most important that the manufacturer keep in mind what the customer wants and make sure that his standards are designed to insure this and not something that the manufacturer thinks should be wanted. In our case, the customer is often not too well informed on the properties of the paper which he wishes. His major concern is that it will run satisfactorily through his equipment and when it doesn't, he is not interested in why; but he wants to make sure that the next delivery will operate successfully. It is up to us, the producer, to set up our own in-plant specifications or standards which will insure proper performance of our product in the customer's plant.

Let us look at two examples which show two different types of standards problems. The first one will consider a technical paper which requires a good many specifications. The second is a paper in which the quality is judged primarily by certain attributes. These two examples, I hope, will demonstrate the methods for establishing a set of standards.

The first paper is transparentizing base stock. This paper is sold for coating with a transparentizing solution and it is then used for tracing paper for the making of blueprints and other forms of reproductions. The customer, or the coater in this case, first wants a sheet of paper which will take his coating solution evenly and uniformly. Secondly, he wants a sheet of uniform transparency, not only in one delivery, but in all deliveries. Exceptional cleanliness, appearance, writing surface, etc., are also important.

To set standards for quality, one must translate these customer desires into some form of measurable or comparative tests. Although most of our testing has developed in the form of "use" tests, very few of them directly measure the characteristics most desired by the customer. Consequently, one must use a combination of available tests and standard samples to gauge his product. Many characteristics of paper oppose each other so that it is important to assign importance to those properties which are of the most importance to the customer.

TABLE I
TRANSPARENTIZING BASE STOCK

Customer Needs	Rating	Available Tests or Standards
1. Accept coating solution	Major	Oil penetration
2. Uniform transparency	Major	Opacity, drip test
3. Cleanliness	Major	Dirt Count - grease check
4. Formation	Minor	Standard sample
5. Correct weight & thickness	Major	Basis weight, caliper, density
6. Color	Minor	Standard sample
7. Good writing surface	Major	Curl test and standard sample
8. Strength and durability	Minor	Fold, tensile, tear

Table I shows a list of the customer needs and opposite that, the available tests which may be helpful in measuring the needs of the customer. It is important to note that many of the customer's requirements are not matched by any one single test.

One recent problem in setting a standard for this type of paper comes under the heading of cleanliness. Normally, production is sampled at regular intervals and a 20-square yard sample is examined very closely for dirt. Standards have been set for the allowable number of defects per sample. However, recently one of our customers was plagued by a tremendous number of brownish spots which showed up in the paper after it had been treated. Laboratory examination showed them to be grease. The difficult part of this problem was that each grease speck, when it was developed by the transparentizing solution, expands nearly a hundred diameters and transfers at least twice and sometimes as many as five times while the paper is being rolled up. Consequently, a very small number of grease specks in a roll of paper present a sizeable problem to our customer. After finding a method for detecting very small specks of grease in the paper, the problem became one of determining what was our allowable tolerance. It was soon found that none of our production could be 100% free from grease. Since the customer was complaining when there were as few as three or four grease spots in 20 square yards of paper, it was evident that the tolerance was very low. We had to find out what was the maximum number of grease specks he could tolerate. We set up a program and carefully sampled all of our current production, which was considered satisfactory by management and the sales department and also sampled past production which had been satisfactory. From this program, it was found normal production could be kept to 5 or less specks per 100 square yards. This we have set as our standard and so far, we have had no complaints from this customer.

Another interesting specification on this paper is the fold test. From the customer's point of view, the fold test is interesting only because fold specifications are sometimes set on his product. This test is also indicative of how well the paper will hold up under handling.

This test is not too important as far as the customer is concerned because it causes no serious production problems if low nor does it exactly measure the strength which this paper should have. Consequently, we classify it as a minor requirement, but nevertheless, it will bring complaints if not up to standard. The customer is primarily interested that none of the paper will test below 500 folds. For a long time, we felt that if we supplied paper which averaged 600, we would be safe in meeting his requirements. An investigation of this showed that we were wrong.

The fold test is interesting statistically because of its large variability. Figure I shows a frequency diagram taken from an average lot of paper. Examination of a good many lots showed that a sigma of 125 could be expected for fold averages (average of 4 tests per sample). To insure that not more than 10% of folds would fall below the minimum of 500, our standard had to be set at 500 + 1.28 sigma or 705. This is now considered our minimum lot average.

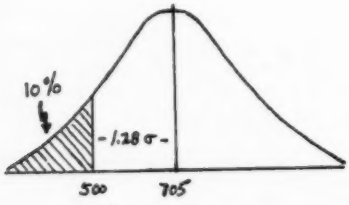


Figure I

The second problem is a type of paper made for the converting trade, to be made into fancy stationery and papetries. Generally speaking, our customers use this paper primarily because of its appearance, feel, brightness, color, etc. Very little stress is put on strength or any other characteristics which lends itself to testing.

TABLE II
SOCIAL PAPERS

Customer Needs	Available Tests or Standards
1. Appearance	Standard sample
2. Good writing surface	Ink feathering test, density, porosity
3. Color	Standard sample
4. Sizing of ink and die stamping	Curl
5. Extreme cleanliness	Sorting
6. Formation	Sorting
7. Strength (sufficient for envelope machines)	Fold

Table II shows the desired characteristics which the customer wants and what tests are available. It is easy to see that the bulk of these characteristics are attributes with no available testing techniques. Because of the very high emphasis on cleanliness and the need to remove all minor blemishes, this paper is 100% sorted or inspected before it is shipped. However, it is well to set some standards before the sorting room, since it is expensive to sort paper and then throw it away for some other defect. Therefore, standards are set on color and finish and on certain technical tests which must be O.K'd. before the paper is passed on for sorting. In the sorting room it is very important that the sorters know what standards they should be sorting to. Setting up standards for these sorters, is quite a problem. Originally, a man who was very closely associated with our customers converting plants and who understood their problem extremely well was able to oversee and follow this operation very closely. He was available at all times to the finishing room foreman to settle any questions of marginal quality. However, retirement has removed him from the scene and it has become necessary to set up a system which can be available to the sorting room foreman as well as to each individual sorter and to their audit inspectors at any time. First, an attempt was made to collect a large number of standard samples, each showing a particular type of defect; ones which were passable and ones which should be rejected. Unfortunately, the number of defects and types of defects became extremely large and consequently, the idea was unsuitable for practical operation. Handling of samples soon reduced them to meaninglessness.

Our present system of sorting standards arose from our efforts to classify the various types of defects. In general, it was found that defects could be broken down into the following categories:

I Technical Defects

II Defects never acceptable regardless of degree.

III Defects where standard samples may be used.

IV Defects where judgment is required as to degree.

We found further that we could classify defects by their effect on the customer. Major defects are ones which would effect the overall quality of a box or carton of paper. Minor defects are those which are scattered randomly and though one sheet is defective, those next to it are not. By following this classification, it is possible to set descriptive samples in many cases and keep the actual number of samples down to a minimum.

EXAMPLE OF A SORTING STANDARD

ECRU KID 40 - WEDDINGS

Use — Sheets and inner envelopes for wedding invitations.
Normal Sorting — 10% and under.
Procedure -- Look-through sort -
Perfect, envelopes, broke

I. MAJOR DEFECTS — Those which will cause a box of stationery to be well below standard in quality - i.e., any running defect.
A. Technical Defects—
1. No paper should be sorted until O.K'd. by the laboratory.

B. Defects never acceptable in perfect paper.
   1. Wrinkles or creases.
   2. Torn sheets.
   3. Flutes.
   4. Grease streaks.
   5. Large spots.
   6. Any minor defect in a large amount.

C. Defects where standards may be used.
   1. Color -- no paper shall be sorted until lot and roll are passed by foreman as being an acceptable match.
   2. Formation -- any sheets showing a more crushed appearance than sample should be removed.

D. Defects where judgment is required.
   1. Watermark -- watermark should be checked by looking through the sheet at regular intervals. Watermark should be legible and clear.
   2. Soft impressions -- impressions in paper surface which will not flatten out on storage must be removed.

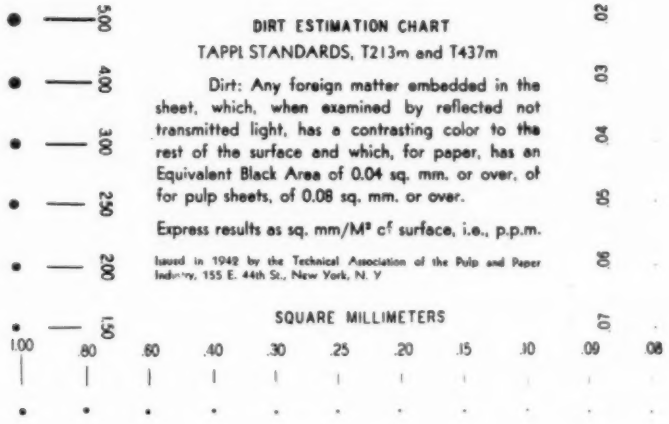
II. MINOR DEFECTS -- Those which affect the quality of an individual sheet. A number of these in any box of invitations will cause complaint or rejection.

A. Defects where visual standards can be used.
   1. Dark spots -- any dark or contrasting spot larger than .40 should be removed or a sheet containing 3 or more specks .25 or larger should be removed.
   2. Light spots or spots of similar color -- One spot of .80 or three of .40 should be removed.

B. Defects where judgment is required.
   1. Foam spots -- foam spots which can be seen from the surface or which appear very bright on look-through should be removed.
   2. Broken surface -- all sheets with broken surface should be removed.

C. Off-weight paper -- Any time the paper is suspected of being heavy or light in weight, the foreman should sample the paper to determine its actual weight. Allowed tolerance is plus or minus 5%.

The actual visual standard samples for this paper are only two, formation and color. Dirt specks are all checked against a TAPPI Dirt Estimation Chart. This shows speck ranging in size from .02 to 5.00 sq. mm. This system has worked well in practice.



The use of these standards has been of a tremendous asset to the individual sorters as well as to the other sorting room personnel. Since each sorter now has available the opportunity to know exactly what standards she should be working to at any given time. As little as possible is left to human judgment, though, of course, this cannot be entirely removed from sorting.

These two methods of approaching standards are quite typical of the problems which we have faced in setting up an over-all picture of standards in our company. Our work is by no means complete since standards have a habit of needing frequent revision. The best that can be hoped for in their case is that they can be kept as up to date as possible and as closely correlated with customer's needs as possible. To aid this, it is important that all customer complaints be channelled through the man charged with keeping up the quality standards. It is only through the complaints of the customer that one is able to keep standards correlated with their needs.

In conclusion, I would like to put one final thought in your minds. The setting of standards by itself does not complete the job. A set of standards is useless if they are not obeyed and followed. It is extremely important that once standards have been set, that they are enforced. This is often a difficult thing to do. In our case, most of our standards previously had been set to the average or median of our production. The fact that they were now set to our lower allowable limit, meant that people were not adjusted to rejecting or holding up paper which was below our standards. If standards are to mean anything, the production people must have confidence in them and must obey them. Customer complaints are, of course, the easiest way to enforce the use of standards. Unfortunately, it often times is difficult to trace the source of the complaint back to the fact that someone let some non-standard material be

shipped. It is far better to bring the mill superintendent or the production foreman into discussion with the Quality Control Department when standards are being set. When the Production Department understands how the standards have been arrived at and why certain ones are important, they are much more likely to have faith and confidence in those standards and consequently use them.

STATISTICAL QUALITY CONTROL APPLICATIONS TO TEXTILE PROCESSING

Roland Archambault
Canadian Celanese Limited

The Picker Process in the Cardroom is one of the most important of the long line of operations which converts bales of tangled fibers into beautiful fabrics. Therefore, it was thought that it might be a good place in which to examine whether or not the statistical philosophy could be applied to textile processing problems.

Since we were not experiencing trouble in meeting the existing weight tolerances, our suggestion to begin here was met with lukewarm enthusiasm.

You will see however, how a careful analysis of past results led to unforeseen improvements.

It may be appropriate now to describe the picker operation. Loose fibers which have been opened from matted bale form, are made into laps. A lap is about 50 yards long, 40" wide and weighs about 41 lbs. It looks like a large roll of absorbent cotton. It is recognized that the spun yarn is usually an extended carbon copy of the variations found in the lap. In an effort to control uniformity, each lap is weighed on a scale. If the weight falls outside the predetermined tolerances, it is returned as waste for reprocessing. Naturally, a key control consideration lies in the selection of the tolerances to be used. In this instance, it was $\pm$ 8 ounces. As each lap was weighed, the machine tender noted the weight on a record sheet. The record was kept for production purposes.

We first suggested that a more effective manner might be to have the record kept in chart form where the tender would place an "X" against the appropriate weight. The weights would be plotted in the sequence in which they were produced. Besides being more convenient for the tender, we wanted to see what was actually taking place as the production proceeded.

An analysis of these charts led us to believe that the picker tolerances could be safely handled. The idea was tried. We have successfully ran with the new tolerances of $\pm$ 4 ounces ever since.

It must be noted that no change was made to the machines, raw material or personnel. The attainment came about through:

1) A rearrangement of a production technique into a control one.

2) The continuing use of the chart to maintain process control.

A tabulated record was made into a visual picture of the quality performance. Once the facts were known, the production line people effected the necessary refinements.

The 50% reduction in process variability has led to higher operating efficiencies in subsequent processes. Higher grading efficiencies and better quality fabric has been produced. Problems of excessively variable yarn sizes have all but disappeared. More of the spun yarn produced now reaches its intended use as Grade "A" fabric. This raw material is not being wasted through fabric degradation.

USE OF SQC IN DETERMINING OPTIMUM COMPONENT TIME BETWEEN OVERHAULS

Allan M. Hull
United Air Lines, Inc.

INTRODUCTION

At some time each of us, and the maintenance man in particular, is confronted with the problem of trying to determine the optimum maintenance or retirement period for his equipment. His problem may be how often should the oil in his car be changed, or how often should it be greased, the spark splugs reconditioned, or when should the engine be overhauled. Perhaps yours is a fleet problem. You have a fleet of trucks, cars, tractors, or airplanes; or a battery of production machines. You are trying to improve quality of service, or manufactured product, or both, and at the same time minimize costs.

Whether or not SQC is new to you, perhaps you are still searching for better SQC techniques to solve your maintenance problems. The techniques I am about to discuss are presented with the hope that they will help you solve some of these problems. In all probability the yardsticks you use for measuring performance are different - - miles, days, cycles, or carloads instead of hours - - which needn't concern you so long as they are valid criterion for measuring performance. Again, you may be more vitally concerned with production schedule, or loss of down-line production manpower, or equipment utilization than with inconvenience to passengers, or safety of operations. Nevertheless, we both have a problem of optimizing quality and costs.

Before delving into our subject, for purposes of clarity and brevity, to avoid confusion, and to allow a more generalized treatment of my subject, I would like to define a few terms I will be using repeatedly.

Age Group - the age bracket or cell boundary, expressed in hours, days, weeks, months, years, miles, cycles, etc. -- whatever yardstick has been found most valid for measuring and expressing performance.

Irregularity - unscheduled replacement, maintenance, or production interruption due to malfunctioning, erratic operation, or becoming inoperative, in many cases involving some degree of safety.

Maintenance Period - the frequency of or interval between complete overhauls, top or light overhauls, minor repairs, adjustments, service or maintenance checks, or inspections, stated in terms of hours, days, months, cycles, miles, etc., as pertains to the problem under consideration.

Unit - the part, component, assembly or mechanism under study.

For purposes of this discussion the maintenance period will be expressed in hours time since overhaul. Your problem may be expressed as miles since overhaul, months since last maintenance check, or days since last inspection, etc., whatever criterion best describes the maintenance operation under surveillance.

For best Results in using the methods of analysis described herein,

the following conditions must be satisfied: (1) reliable and timely performance data must be available reflecting both scheduled and unscheduled maintenance operations, including the time since the last maintenance operation under consideration, (2) the period being sampled must be representative of the conditions to which the decision element will be applied; i.e., maintenance practices and procedures, operating limits and environment, being careful to avoid questionable areas, change-over or transitionary periods, (3) for best results the sample should include a minimum of 100 units, scheduled and unscheduled combined, preferably representing a calendar period equivalent to the maintenance period of the unit, (4) the problem must be clearly defined, the purpose of the study clearly stated, and all parameters of the problem brought into sharp focus in terms of the analysis.

ACTUARIAL ANALYSES

As production processes become more highly mechanized, and with the advent of automation, the need for more scientific methods of determining optimum maintenance periods has increased manifold. The actuarial or mortality type of analyses covered in this paper is presented to help solve this problem.

In considering optimum maintenance periods, three of the most frequently asked questions are:

(1) How do the actuarial rates of the different age groups compare?

(2) When should the unit be maintained for optimum performance?

(3) When should the unit be maintained to minimize costs?

In answering the above questions our analysis must compensate for the reduction in the number of units left in service in each age group -- a factor frequently overlooked in studies of this type. Limiting consideration to only unscheduled removals, or failing to account for scheduled removals, does not take the universe into account, i.e., the total units in service in the age group. Nor does it recognize that some scheduled removals may occur in the lower age groups as well as in the higher age groups, depending upon existing maintenance policy.

The answer to the first question, "How does the actuarial rate in each age group compare?", is found by dividing the total hours operated in each age group by the number of irregularities in the same age group -- an exposure/experience relationship. This is plotted as a broken line (- - -), and is known as a non-cumulative curve (See Figure 1).

The second question, "When should the unit be maintained for optimum performance?" is answered in much the same manner as was the first question, except that each succeeding age group is larger, and each age group always starts with zero time since the last maintenance period. The total hours operated by all units to each preselected point in the maintenance period is divided by the total irregularities for the same age group. The result is the performance that was experienced to that point in the maintenance period. This is plotted as a solid line (——) and is called a cumulative curve (see Figure 1). Each point of the curve is the performance we would expect if the unit were maintained at

this point. The high point in the cumulative curve is the point at which the unit should be maintained for optimum performance. This is the point at which the slope of the cumulative curves changes from positive to negative, and the non-cumulative curve drops below the cumulative curve.

With this briefing on the basic concepts behind actuarial studies, let's consider an actual problem. The format covered by Figure 1 has been designed to facilitate data tabulation, analysis, presentation and interpretation. The maintenance period usually is divided into approximately 20 equal intervals. However, the number of intervals and their size may be varied to give greater sensitivity in certain areas of the maintenance period, as the lower or higher age groups. First, the irregularities are tallied according to the age group, or cell in which the irregularity occurred under item ① , Figure 1. In this step it may be desirable to categorize the irregularities into arbitrary groups as to cause or severity of the irregularity to allow treatment of weighted defects for later analysis.

Likewise, the scheduled maintenance operations are catalogued by age group under item ② , Scheduled Removals. This step reflects early or out of phase maintenance operations and properly credits them into our maintenance study. It also provides a basis for evaluating maintenance policies and practices. If low time scheduled maintenance operations were performed, the decision must be reached as to how they should be treated in the analysis. This decision is predicated largely upon the circumstances that led to the premature maintenance; i.e., (1) was this decision for convenience and purely arbitrary?, or (2) was it as a result of an inspection, a check, or through some other indication that the maintenance operation was warranted? In the former case, it should be considered as an irregularity in that, or a higher, age group. (See also discussion in second paragraph following Figure 9.)

Item ③ , the Number Left in Service is found by subtracting items ① plus ② from item ③ for the previous age group, i.e., the number in service at the beginning of the age group. This step is repeated consecutively for each of the age groups.

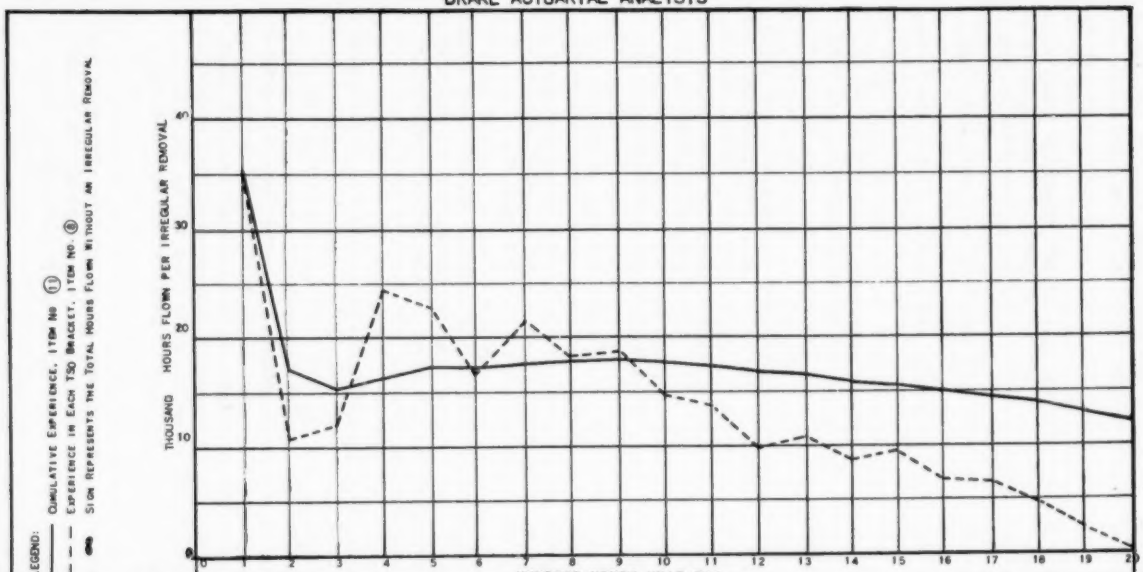
Under items ④ , ⑤ and ⑥ , the operating hours are catalogued for the units tallied under ① , ② and ③ , respectively. To simplify calculations, items ④ and ⑤ are found by multiplying items ① and ② by one-half the age bracket in hundred hours -- the use of "hundred hours" simplifies carrying decimals. One-half the cell interval is used since it is assumed for simplicity that, on the average, the removal took place at the cell midpoint. In actual practice this has worked out very satisfactorily when results are compared with actual times. Item ⑥ is calculated by multiplying item ③ by the age bracket in hundred hours, since these units remained in service during the full cell interval.

Item ⑦ is the total operating hours accumulated by all units that operated in that age group, the exposure in that age group. It is the sum of the operating hours under items ④ plus ⑤ plus ⑥ .

Item ⑧ , the experience in each age bracket, is found by dividing the total hours operated (exposure) in the age group, item ⑦ , by the number of irregularities (experience) in that age group, item ① .

FIGURE 1

BRAKE ACTUARIAL ANALYSIS


LEGEND:
CUMULATIVE EXPERIENCE, ITEM NO (11)
EXPERIENCE IN EACH TSO BRACKET, ITEM NO. (8)
SIGN REPRESENTS THE TOTAL HOURS FLOWN WITHOUT AN IRREGULAR REMOVAL
THOUSAND HOURS FLOWN PER IRREGULAR REMOVAL
HUNDRED HOURS UNIT TSO

																					TOTAL
(1)	NO. IRREGULAR REMOVALS	8	24	19	9	9	11	8	9	8	9	9	11	9	10	8	10	9	10	14	12	216
(2)	NO. SCHEDULED REMOVALS	3	6	4	2	9	7	2	3	8	3	2	3	2					1	5	12	72
(3)	NO. LEFT IN SERVICE	277	247	224	213	195	177	167	155	139	127	116	102	91	81	73	63	54	43	24	0	288
(4)	100 HRS. ACCUM. ON (1)	4	12	9.5	4.5	4.5	5.5	4	4.5	4	4.5	4.5	5.5	4.5	5	4	5	4.5	5	7	6	
(5)	100 HRS. ACCUM. ON (2)	1.5	3	2	1	4.5	3.5	1	1.5	4	1.5	1	1.5	1					0.5	2.5	6	P
(6)	100 HRS. ACCUM. ON (3)	277	247	224	213	195	177	167	155	139	127	116	102	91	81	73	63	54	43	24	0	75-1
(7)	Σ (4)+(5)+(6)	282.5	262	235.5	218.5	204	186	172	161	147	133	121.5	109	96.5	86	77	68	58.5	48.5	33.5	12	
(8)	(7) ÷ (1) = EXP IN BRACKET	35.3	10.9	12.4	24.3	22.7	16.9	21.5	17.9	18.4	14.8	13.5	9.9	10.7	8.6	9.6	6.8	6.5	4.9	2.4	1	
(9)	ITEM (7) CUMULATIVE	282.5	544.5	780	998.5	1203	1389	1561	1722	1869	2002	2123	2 232	2329	2415	2492	2560	2618	2667	2700	2712	
(10)	ITEM (1) CUMULATIVE	8	32	51	60	69	80	88	97	105	114	123	134	143	153	161	171	180	190	204	216	
(11)	(9)÷(10) = CUM. EXPERIENCE	35.3	17	15.3	16.6	17.4	17.4	17.7	17.8	17.8	17.6	17.3	16.7	16.3	15.8	15.5	15.0	14.5	14.0	13.2	12.5	

This gives the actuarial rate in each age group, the answer to the first question above. This result, the experience in the age group, is non-cumulative, is plotted as a broken line (- - -), and is a valuable clue in localizing problem areas and effecting corrective action. By definition all points are plotted to the right hand margin of the cell, see Figure 1. When there are no irregularities in a particular age group, the total units operated in the age bracket are posted with an infinity sign (∞) over that point on the curve.

Item (9) is item (7) cumulative, from zero time to each age group, i.e., total time operated by all units up to that particular point in the maintenance interval.

Item (10) is the cumulative number of irregularities from zero time to each age group. It is the cumulative totals of item (1), left to right, to that point in the maintenance period.

Item (11) is the Cumulative Experience of all units to that point in the maintenance period -- the performance we could expect if this were the maintenance period of the unit. Item (11) is calculated by dividing the cumulative hours operated, item (9), by the cumulative number of irregularities from zero time to that particular point in the overhaul period, item (10). This is the cumulative curve, which is plotted as a solid line (——), see Figure 1. This answers question 2, "When should the unit be maintained for optimum performance?"

When the non-cumulative curve stays above the cumulative curve, performance is better than the average performance to that point. When the performance in the individual age groups falls consistently below the cumulative curve, the non-cumulative curve indicates that performance in these age groups is poor, has deteriorated, and is below the average to that point. This curve indicates that the overhaul period is too long and for optimum performance should be reduced.

The cumulative curve shows the cumulative experience to any given point in the overhaul period. It shows the performance of all units from zero time to each point in the overhaul period represented on the abscissa. If the sample taken is a representative sample, and represents the process or product being produced, each point on this curve represents the performance that can be expected if the unit is overhauled at that particular point in the maintenance period. For optimum performance, the component must be overhauled at the highest point on the cumulative curve. If this point occurs at the end of the overhaul period, a further increase in overhaul time may be warranted. A positive slope to the curve may be an indication that the overhaul period should be extended, while a negative slope may indicate that the overhaul period should be reduced.

If the answer to the optimum overhaul period is not obvious, further analysis is required, particularly of the data section of the curve and of the Premature Removal Chart. An orderly tabulation of data, as in the Premature Removal Chart, see Figure 2, often is an invaluable tool in reflecting correlation in data and providing a simple solution to otherwise seemingly complex problems. The Premature Removal Chart shows the primary cause of trouble, the number of replacements for each cause, the time since overhaul relationship, and the monthly or seasonal trend of irregularities. It focuses attention on the nature and severity of irregularities, localizing the problem for expedient corrective action.

The example in Figures 1 and 2 was selected since it represents both high and low time irregularities and shows how the Premature Removal Chart and Actuarial Curve complement one another. The poor performance in the 100 to 300 hour age bracket of the Actuarial curve, Figure 1, is shown as primarily due to "Piston, 'O' Ring Damage", item 17 , on the Premature Removal Chart and peaked during the 10th and 11th months. This problem is evaluated along with the other irregularities in the lower age groups, and is suggestive of an overhaul, assembly or personnel error, or a poor batch of material. Low time failures frequently are more pronounced in the first age group, i.e., zero to 100 hours. If this were the case, the first point on the non-cumulative curve (Figure 1) would be lower, say at 700 to 900 hours. This in turn would be reflected on the cumulative curve as in Figure 6. Item 24 , in contrast to item 13 represents a wear problem in the higher age groups and indicates that the overhaul period is open to question. In cases of this type there may be a choice between reducing the overhaul period or testing different types of material in an endeavor to find a better material. In the latter choice, careful test design and analysis is essential to insure reliable test results.

The actuarial curve accurately reflects performance in each age group and the performance that could be expected if the unit were overhauled at each point on the cumulative curve. The Premature Removal Chart, on the other hand, tells us what is causing difficulty, the frequency, the relationship to the maintenance period, and the monthly trend. Together they are effective tools for localizing and effecting corrective action.

In actuarial studies, often it is desirable to treat several age groups together to get a clearer picture of performance in the different parts of the maintenance period, i.e., the first half compared with second half, etc. This is done by dividing the total hours operated during the age group in question (in Figure 1, found by adding item ⑦ for the interval) by the total irregularities during the same age group (found by adding item ① for the same interval). In this manner, one portion of the maintenance period can be compared with any other portion of the maintenance period. Also, the percentage of units remaining in service at any point in the overhaul period is found by dividing the Number Left in Service at that point, item ③ by the total number of units in the sample. Likewise, we can determine the average age of the units in the sample by dividing the Total Hours Cumulated by all units, the right hand figure in item ⑨ , by the total units in the sample. The percent defective ($\bar{p}$) for the sample is shown in the right hand margin of the data section and is found by dividing the total Number of Irregularities by the total units in the sample.

In instances where one type of defect or irregularity is more serious than others, weighted defect values can be assigned to the individual irregularities represented in item ① . In this manner the curve will clearly and accurately portray the relationship between hazardous conditions and time since overhaul.

Instead of a rectilinear coordinate scale as used in Figure 1, an arithmetical progression or a log scale may be used. The latter two will accommodate a much wider range of values than the rectilinear coordinate scale, but may lead to confusion and errors in interpretation.

Careful analysis of the Actuarial Curve and Premature Removal Chart

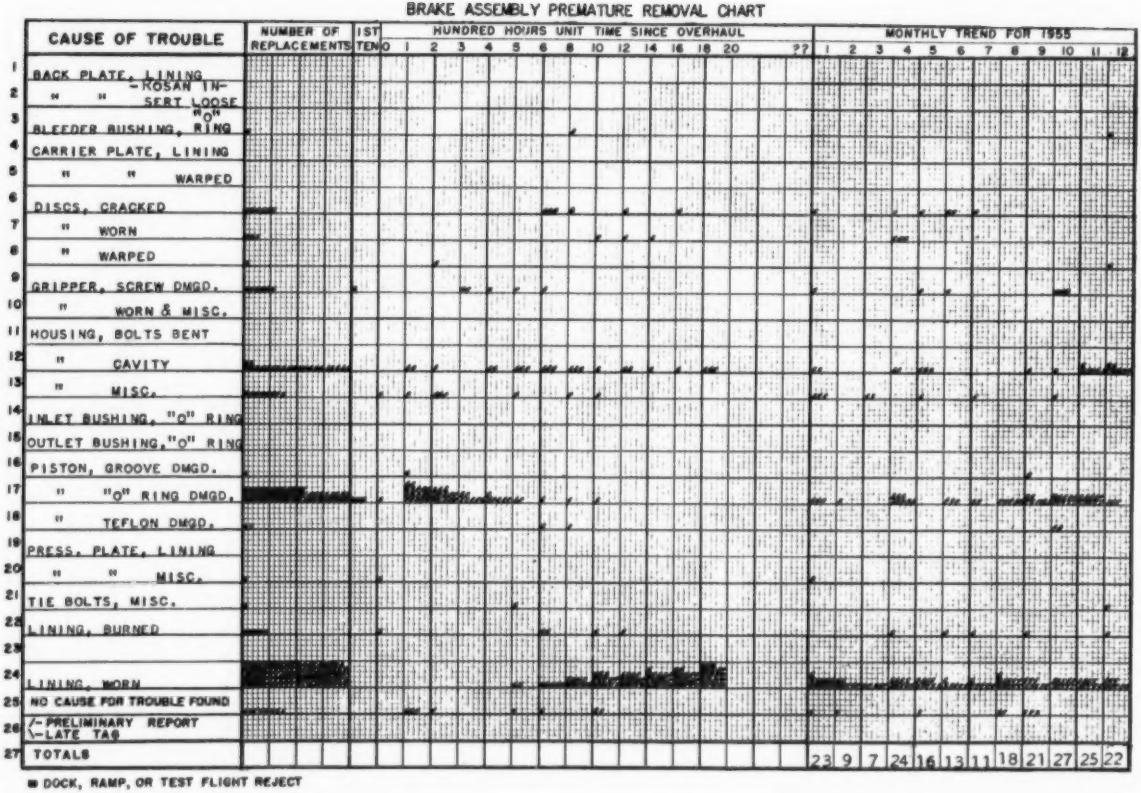

BRAKE ASSEMBLY PREMATURE REMOVAL CHART
CAUSE OF TROUBLE
NUMBER OF REPLACEMENTS
1ST TEN
HUNDRED HOURS UNIT TIME SINCE OVERHAUL
0 1 2 3 4 5 6 8 10 12 14 16 18 20 27
MONTHLY TREND FOR 1955
1 2 3 4 5 6 7 8 9 10 11 12
1 BACK PLATE, LINING
2 " " -ROSAN INSERT LOOSE
3 BLEEDER BUSHING, "O" RING
4 CARRIER PLATE, LINING
5 " " WARPED
6 DISCS, CRACKED
7 " WORN
8 " WARPED
9 GRIPPER, SCREW DMGD.
10 " WORN & MISC.
11 HOUSING, BOLTS BENT
12 " CAVITY
13 " MISC.
14 INLET BUSHING, "O" RING
15 OUTLET BUSHING, "O" RING
16 PISTON, GROOVE DMGD.
17 " "O" RING DMGD.
18 " TEFLON DMGD.
19 PRESS. PLATE, LINING
20 " " MISC.
21 TIE BOLTS, MISC.
22 LINING, BURNED
23
24 LINING, WORN
25 NO CAUSE FOR TROUBLE FOUND
26 /-PRELIMINARY REPORT
\-LATE TAG
27 TOTALS
23 9 7 24 16 13 11 18 21 27 25 22

FIGURE 2

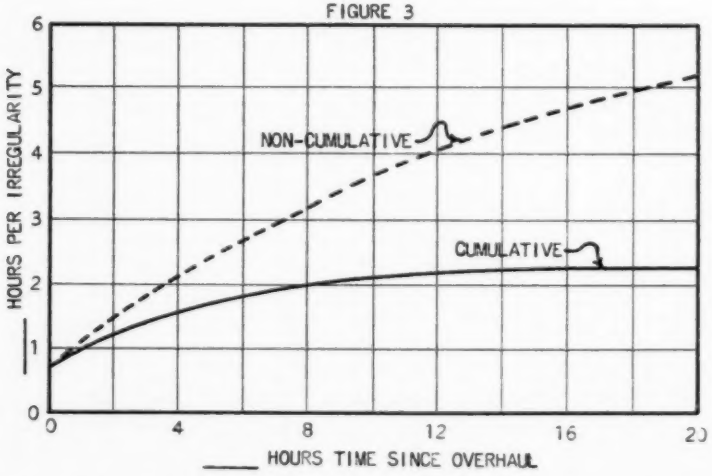
■ DOCK, RAMP, OR TEST FLIGHT REJECT

often leads to a choice of solutions to the problem, such as changes in maintenance or operating procedures, more frequent servicing of a trouble area, modifications of the unit, or a change in overhaul or service periods — all are ways of eliminating the "weak link" in the chain. Thus, not only are we able to determine the optimum maintenance period, but even more important, we are able to further improve the quality of the product and at the same time reduce maintenance costs. The final decision should take the safety and economic factors into account, and the condition of the units at the end of the maintenance period.

TYPICAL ACTUARIAL CURVES

To gain a little experience in interpreting actuarial curves, let us consider some of the more typical types of actuarial curves encountered in analyzing airline maintenance problems. Interpreting these curves will illustrate the value of the data section of the Actuarial Curve, (see Figure 1), the Premature Removal Chart, (see Figure 2), and the value of other SQC tools in solving maintenance problems.

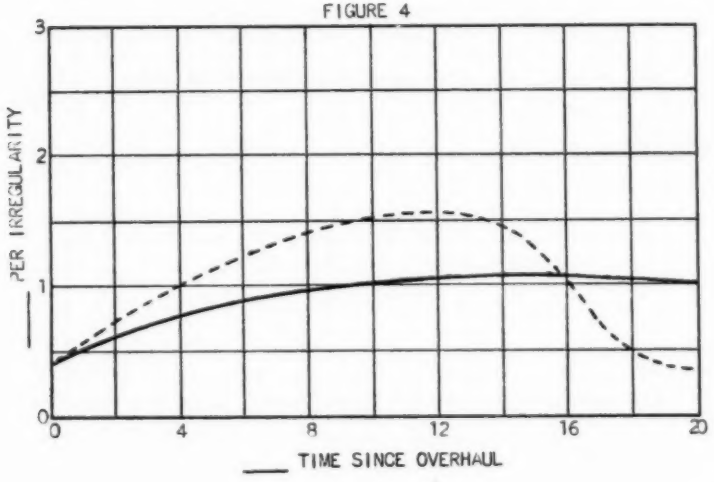
FIGURE 3



In Figure 3, the strong positive slope to the non-cumulative curve, the experience in each age group, shows that the probability of survival increases rapidly with age -- the older the part the better its chance for survival. The positive slope to the cumulative curve indicates that the over-all performance too is improving with age, but at a much slower rate. The spread between the two curves, the difference in the degree of positiveness, suggests that, due to a high actuarial in the lower age groups, few parts remain in service, and that while their performance is very good, their effect upon the cumulative curve diminishes as the time since overhaul increases. A curve with this characteristic may be indicative of a high initial mortality rate due to poor material or workmanship. Or, it may indicate a "weeding out" or selective process as a result of incompatibility between two or more parts. In this case, parts are rejected until the right combination of parts or tolerances are found. Examples are a transmitter and indicator, carburetor and mixture control unit, etc. The curve in Figure 3 is typical of certain types of

electronic components with a high "infant" mortality rate due to tubes and other electronic components. This curve indicates that the overhaul period can be extended indefinitely. However, the fit of the overhaul period should be reviewed when improved types of tubes or transistors are installed. An $\bar{X}$ and R chart may reveal the real cause of the difficulty, as parts being produced on the high, or the low side of tolerance.

FIGURE 4



The cumulative curve in Figure 4 is similar to that of Figure 3. However, note the difference in the experience in the individual age groups (non-cumulative curve). Performance in the individual age groups reaches its peak at age 12, then begins to drop off. It crosses the cumulative line at age 16. For optimum performance, the maintenance operation should be performed at this point. However, it should be noted that while the performance in the succeeding age groups is very poor, it has but very little effect upon the cumulative curve. This suggests that few units remain in service in terms of the total number of units at the start of the sample. Hence, it may not be practical, or economically sound, to maintain the unit at this point in view of the very small effect upon the cumulative curve. The final decision should take into consideration (1) whether or not high time irregularities are more serious than low time failures (The Premature Removal Chart will answer this question), (2) whether high time failures are more costly with respect to repair costs, and (3) whether they are more likely to result in lengthy delays and schedule interruptions.

This curve indicates that the time since overhaul should not be increased, and possibly should be reduced, contingent upon the considerations enumerated above, and the results of the cost analysis discussed in the next section.

FIGURE 5

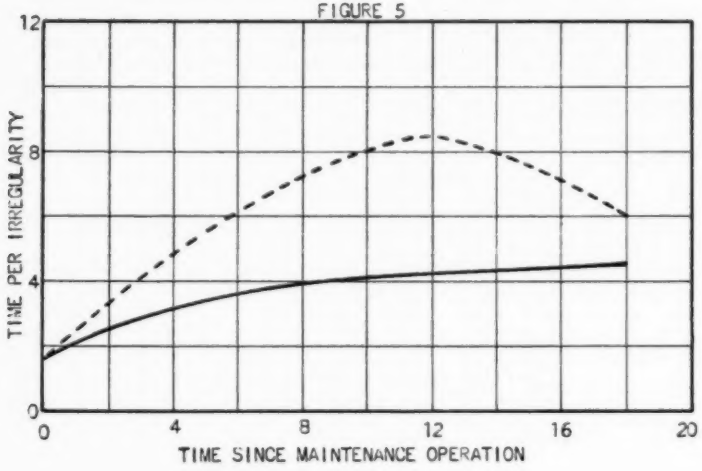
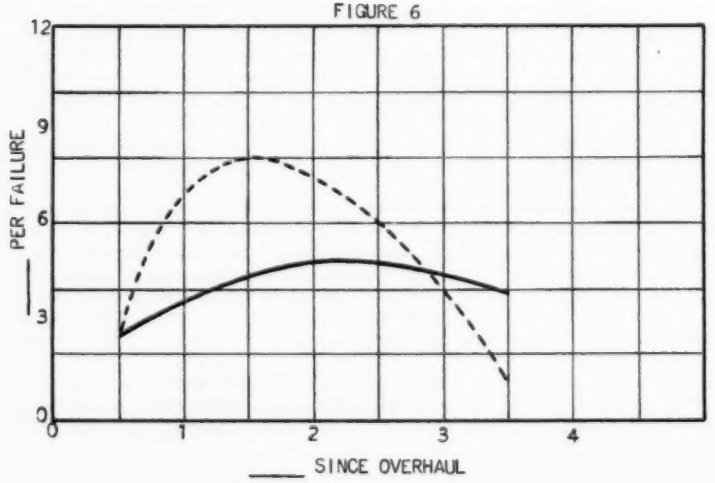


Figure 5 illustrates another typical actuarial curve. While the cumulative curve has a positive slope, at age 12 the slope of the non-cumulative curve changes from positive to negative. If both curves are extrapolated, they would intersect at age 20. This suggests that the maintenance period is about right, or possibly could be increased to 20. However, it should not be increased to 20 until a representative sample of age 18 units have been inspected and found satisfactory for further service.

FIGURE 6



In Figure 6, the slope of the cumulative curve changes from a positive to a negative slope at the 2½ age group. For optimum performance the unit should be maintained at this point. However, here again, the Premature Removal Chart should be consulted to ascertain the assignable cause of trouble, its nature and severity, and whether or not any other type of corrective action is in order. By looking for the "weak link in the chain" we frequently find that corrective measures of a very minor nature yield very large returns in improved performance and/or reduced maintenance costs. Careful attention should be given to units that show a sharp rise in performance in the very early age groups. Curves manifesting this characteristic are suggestive of an overhaul, handling, installation, stocking, or shipping problem -- one that easily may be rectified. Often the Premature Removal Chart will give a clue to the source of the difficulty.

FIGURE 7

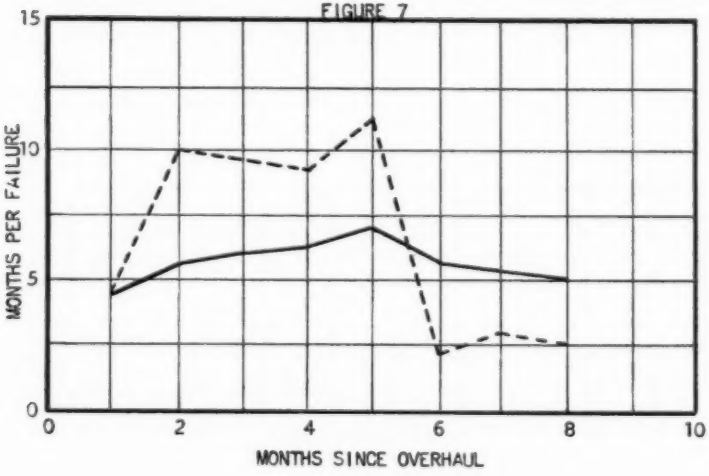


Figure 7 is typical of a unit with a problem in the first age group, and shows the advantage of keeping the age groups small to avoid hiding problem areas. The Premature Removal Chart should be consulted to ascertain the nature of the problem, whether it is a materials, overhaul, handling, installation or other type problem. Figure 8, on the other hand, shows a unit with very excellent performance in the first age group. The units in both Figures 7 and 8 show marked deterioration in performance in the higher age brackets. Here again, the Premature Removal Chart will provide valuable clues as to the cause and nature of the problem, will provide a basis for deciding whether a change in overhaul, maintenance, or operating procedures, etc. is in order, or the time between overhauls should be reduced.

FIGURE 8

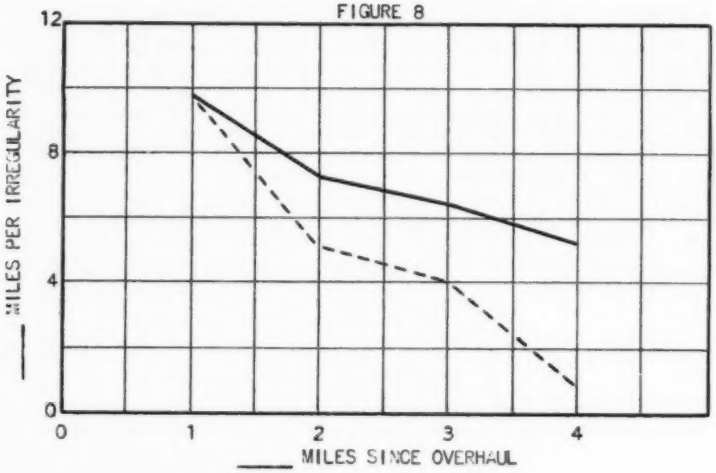


FIGURE 9

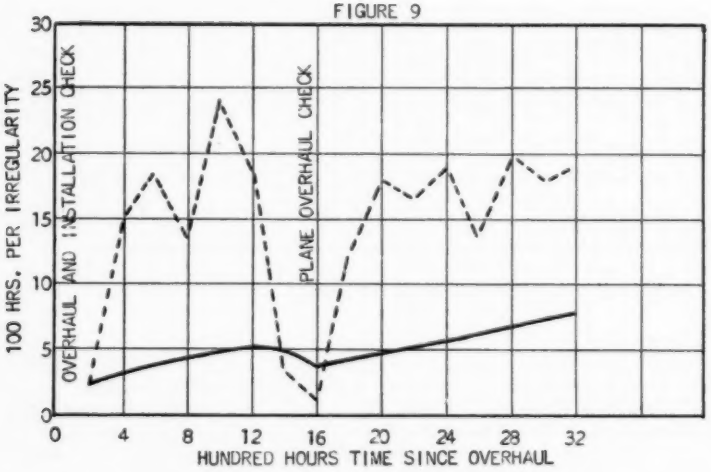


Figure 9 is another interesting type of actuarial curve. The 0 to 2 and 14 to 16 age groups appear as problem areas, perhaps areas that have something in common. Consulting the Premature Removal Chart often will reveal the cause of the difficulty. Too reflecting upon the possibility of a maintenance operation, procedure, or check in the 14 to 16 age group may uncover the cause of the difficulty.

In analyzing actuarial curves as the above, service or maintenance checks performed at various intervals during the overhaul period should be evaluated for effectiveness. It is wise to indicate these checks on the abscissa of the curve, see Figure 9. Removals as a result of a maintenance check must be treated with caution and consideration. First, a very definite viewpoint must be decided upon in advance to assure treatment of these removals in their proper relationship. Too, the maintenance policy which resulted in their removal must be critically evaluated. In other words, did the removal of these units from service prevent an impending failure, and if so, approximately when would it have occurred; or was the removal really warranted, or just a "shot in the dark"? If the removals are truly "preventive maintenance" and eliminate unscheduled changes, service or production interruptions, they can be intelligently analyzed. One method of analysis is to consider them as "failures" in the same or the next higher age group (depending upon when you estimate they would have failed in service). An actuarial curve drawn on this basis will reflect performance had they been allowed to continue in service, i.e., operated to failure. Now, if the second actuarial curve is drawn, this time considering removals as a result of maintenance checks as "scheduled removals", the difference or area between the two cumulative curves represents the improvement in performance as a result of the maintenance check. In this manner the effectiveness of the maintenance check can be evaluated.

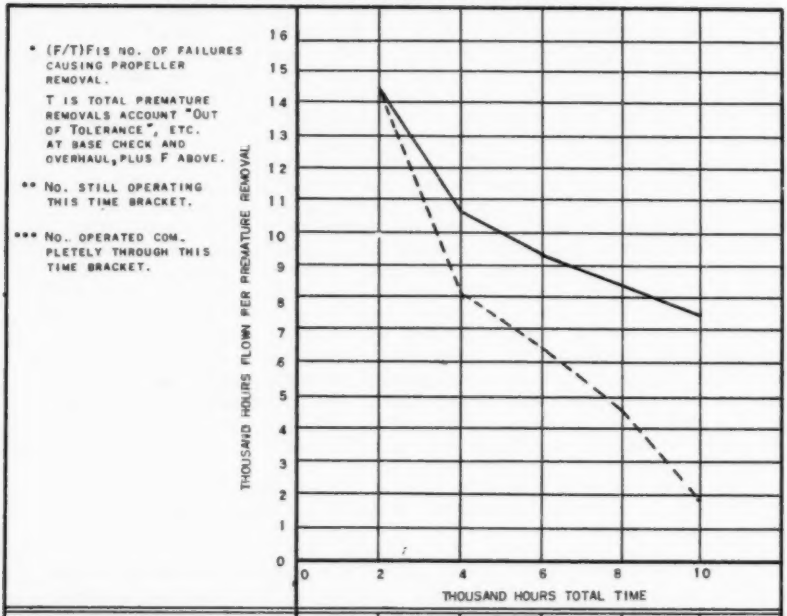
Cost curves (see next section) drawn on the same basis will give a sharp insight into the effectiveness or logic of the maintenance program.

If failures follow a more or less uniform pattern irrespective of the maintenance check, or if failures occur soon after the maintenance check, they suggest that the maintenance check either is ineffective in pin-pointing potential failures, or is aggravating rather than eliminating failures.

Occasionally actuarial curves exhibit a bimodal characteristic, as Figure 9, indicating poor performance in two different areas of the overhaul period. In general, this suggests two or more assignable causes. The poor performance early in the maintenance period suggests an overhaul, handling, stocking, shipping, or storage problem, while the poor performance later in the maintenance period may be an indication that the maintenance period is too long, or some other factor is at work. However, a review of the Premature Removal Chart may provide the required clue to the solution of both problems.

Caution must be exercised in selecting a suitable sample, and in analyzing and interpreting the curves to be sure that the sample is of adequate size, that it is a representative cross section of the product to be sampled, and that bias or bimodality is not injected into the picture by taking a sample representing two different types or models, production processes, maintenance or operating procedures. After a unit has been modified, generally it is desirable to take a sample both before and after the change, and to compare the results to evaluate the efficacy of the modification. This gives a valid measure of the two processes and provides a scientific basis for management decisions.

FIGURE 10
ACTUARIAL CURVE FOR PROPELLER DE-ICER BOOTS



1* No. Premature Removal (F/T)	13/34	18/49	8/43	6/32	5/23	50/18
2** No. Still In Service	5	6	21	33	20	85
3*** No. Completed This Bracket	227	172	108	43	0	266
4 100 Hrs. Accum. on 1	340	490	430	320	230	
5 100 Hrs. Accum. on 2	50	60	210	330	200	
6 100 Hrs. Accum. on 3	4540	3440	2160	860	0	
7 Σ 4+5+6	4930	3990	2800	1510	430	
8 7÷1 = Exp. In Bracket	145.0	81.4	65.1	47.2	18.7	
9 Item 7 Cumulative	4930	8920	11720	13230	13660	
10 Item 3 Cumulative	34	83	126	158	181	
11 9÷10 = Cum. Experience	145.0	107.5	93.0	83.7	75.5	

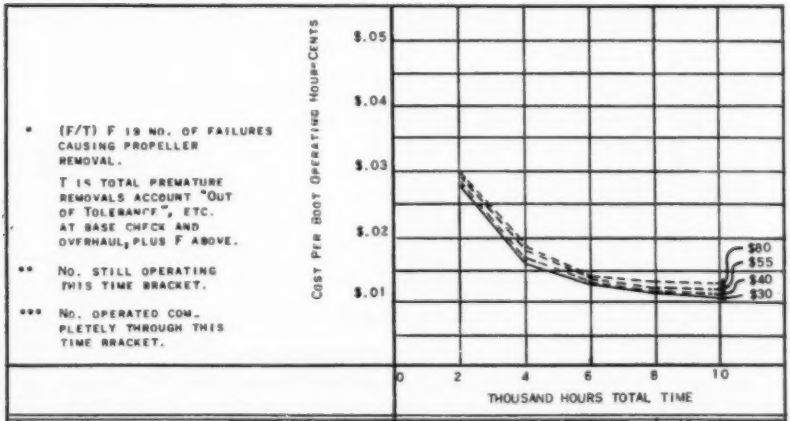
Figure 10 is typical of units that show a gradual deterioration with age. This unit indicates a high quality product in the low age groups. However, do not make the early age groups too large, or low time failures will be hidden in the sample.

When the cumulative curve has a negative slope it is difficult to determine when the unit should be maintained. Any decision or point selected appears arbitrary. Often the decision is based on an "acceptable" level of performance, which in itself is usually a matter of opinion rather than based on scientific study. In cases of this type, the economy curve presented below provides a scientific method of analysis, providing the parameters of the problem can be resolved.

COST ANALYSES

With this experience in interpreting actuarisl curves, let us consider a cost type of analysis that is an outgrowth or counter part of the actuarial studies just described. Briefly, in our cost analysis we will endeavor to show the cost per operating hour if the unit were maintained at preselected points in the maintenance period. These preselected points may be the same or longer than covered in the actuarisl analysis to key in with other logical maintenance operations or cycles. In the cost analysis, an effort is made to "price out" the total cost (tangible and intangible) of all irregularities, and to show the cost if the maintenance operation in question were performed at each of the preselected points in the maintenance period. The results are expressed in costs per operating hour, see Figure 11 below.

FIGURE 11
COST CURVE FOR PROPELLER DE-ICER BOOTS



(1) No. Irregular Removals (F/T)	13/34	18/49	8/43	6/32	5/23	
(2) No. Still In Service	5	6	21	33	20	
(3) No. Completed this T. S. O. Bracket	227	172	108	43	0	
(4) Cost of (1) (F at $30.59 plus T @ $51.98)	$2165	$3098	$2480	$1847	$1348	
(5) Cost of (2) (@ $51.58 per Case)	$ 258	$ 309	$1083	$1702	$1032	
(6) Cost of (3) (@ $51.58 per Case)	$11709	$8872	$5571	$2218	$ 0	
(7) Item (4) Cumulative	$ 2165	$5263	$7743	$9590	$10938	
(8) Item (5) Cumulative	$ 258	$ 567	$1650	$3352	$ 4384	
(9) Σ (6)+(7)+(8)	$14132	$14702	$14964	$15160	$15322	
(10) Hundred Hours Operated (Item (3), Fig. 10)	4930	8920	11720	13230	13660	
(11) Cost Per Hour Operated ((9)÷(10)÷100)	$.0287	$.0165	$.0128	$.0115	D.0112	
(11) F @ $40	.0289	.0168	.0131	.0118	.0116	
(11) F @ $55	.0293	.0174	.0136	.0123	.0121	
(11) F @ $80	.0300	.0182	.0144	.0132	.0130	

TABLE I

(a)	Material cost of one boot . . . . . (heater element)	$48.45
(b)	Labor cost of replacing one boot. . . . . (1½ hrs. at $2.35/hr.)	3.53
(c)	Labor cost per boot when set of 3 boots replaced . . . (4 man hrs. at $2.35/hr.) / 3	3.13
(d)	Labor cost of replacing one propeller in field . . . . (7½ hrs. at $2.35/hr.)	17.63
(e)	Average Icex (chemical deicer) cost per boot failure . . (12 applications at $.62 each, based on: 1/6 man hr. at $2.35/hr. $.39 per application; 1/16 qt. Icex at $3.69/qt. $.23 per application; Total of $.62 per application)	7.44
(f)	Shipping costs per failure . . . . . (1) Propellers were shipped on space available basis. (2) Handling costs estimated at $20.00. (3) 27.6% of failure replacements at other than overhaul & required handling equal 27.6% of $20.00 equal $5.52.	5.52
(g)	Delay Costs . . . . . (Sample of 4 month period averaged 2½ delays per month, with average duration of 7 minutes.)	Negligible (Difficult to estimate)

F - Failures in service causing unscheduled propeller replacement

T - Defective boots (outside electrical limits) found during scheduled propeller base check or overhaul, plus F, above

F = (a)+(b)+(d)+(e)+(f)+(g) above - $51.98 + $30.59	$82.57
T = (a)+(b)	51.98
Note: The difference, F-T, represents the cost of a Failure	$30.59

COST ALLOCATIONS FOR ITEMS ON COST CURVE

Item 1 - T at $51.98 + F at $30.59	
*Item 2 - (a) + (c) above	$51.98
*Item 3 - (a) + (c) above	$51.98

*Items 2 and 3 are based on assumed retirement in each age group represented on the abscissa.

Many kinds of mechanical breakdowns are measurable and can easily be converted to dollar costs. Others, as customer good will, are more difficult to evaluate. Nevertheless, the problem is none the less real. Unpredictable mechanical break-downs are costly for many reasons. Among the most costly are (1) loss of customer good will, (2) failure to meet production schedules, (3) down-line production schedule interruption, (4) continuing manpower and equipment costs while equipment is being repaired, (5) stockpiling to "hedge" against interruptions through breakdown, and (6) cushions in production schedules to forestall serious production tie-up due to equipment failures. Figures 10 and 11 show the actuarial and cost curves for a typical study and the data sheet (Table I) showing cost allocations. When the cost curve begins to flatten out, it indicates that the point of diminishing returns is being reached, and that there is little or no gain by going beyond that point since it is very probable that operating costs will rise again, i.e., the curve is parabolic. On the other hand, if the slope of the curve is still sharp, it indicates that the maintenance period may be extended to effect a further reduction in costs. It is wise to consult the Premature Removal Chart to ascertain the nature of failures in the higher age groups, and to inspect units to ascertain whether or not extending the maintenance interval appears warranted.

In Item (1) , Figures 10 and 11, the number to the left of the slash mark (/) shows the number of in-service failures (F) , while the number to the right of the "/" mark shows the total (T) premature replacements due to all causes in each age group. Table I shows that the cost of an in-service failure as $30 above the cost of replacing a questionable part at a scheduled maintenance period.

To get a clearer picture of the effect of different pricings of in-service failures on the decision element, the cost of a failure was increased from $30 (solid line) to $40, $55, and $80 (broken lines). In this example, see Figure 11, all four curves are essentially parallel in all age groups. In the 8 to 10 thousand hour bracket the slope of the curve approaches zero for all four "pricings", indicating that the point of diminishing returns has been reached. The point of minimum cost is in the 8,000 to 10,000 bracket with indications that costs will increase if the component is continued in service beyond this time bracket.

In most cases, the pricing of failures has a strong influence on when the unit should be maintained to optimize costs and illustrate the importance of reliable cost data in decision making.

CONCLUSION

During the 9 years our DC-6 aircraft have been in operation, the Premature Removal Rate has been reduced by 55% and the time between overhauls has increased by 300%. This six fold gain is the result of the coordinated effort of many activities within United Air Lines -- the result of improvements effected by engineering, our overhaul shops and by the manufacturer, of training, of improved maintenance equipment and facilities, and of changes in maintenance practices and procedures. The SQC tools described herein have played an important role in augmenting this program. These tools have made it possible to pin-point problem areas, effect corrective action, and to consolidate our gains by increases in overhaul times where warranted.

To optimize quality and costs, determination of the optimum main-

tenance period is an important ingredient. With the increasing complexities of our production facilities, we can no longer rely on individual judgement or intuition to guide us in establishing maintenance periods. We are forced to use more scientific methods of analysis in solving our problems. The mortality and economy types of analyses are presented to help fulfill this need.

"A STATISTICAL QUALITY CONTROL APPROACH TO WEIGHTS AND MEASURES PROBLEMS"

Edward P. Lee
General Foods Corporation

A majority of the food packages packed in the United States and Canada are required by law to maintain an average fill equal at least to the quantity stated on the label. On the other hand, only a few packers are unaware of the economic forces that are focusing increased attention on package fill. The packer that can afford to overfill indiscriminately is becoming increasingly rare. The emphasis on yield and control of overfill is apparent in the literature of the trade magazines. The packer, therefore, has two limitations: an upper limit that is economic and a lower limit of law and integrity.

Among the problems that confront him are: 1. How to control the average at the desired level. 2. How to establish an average level that has a high probability of meeting the legal limitation.

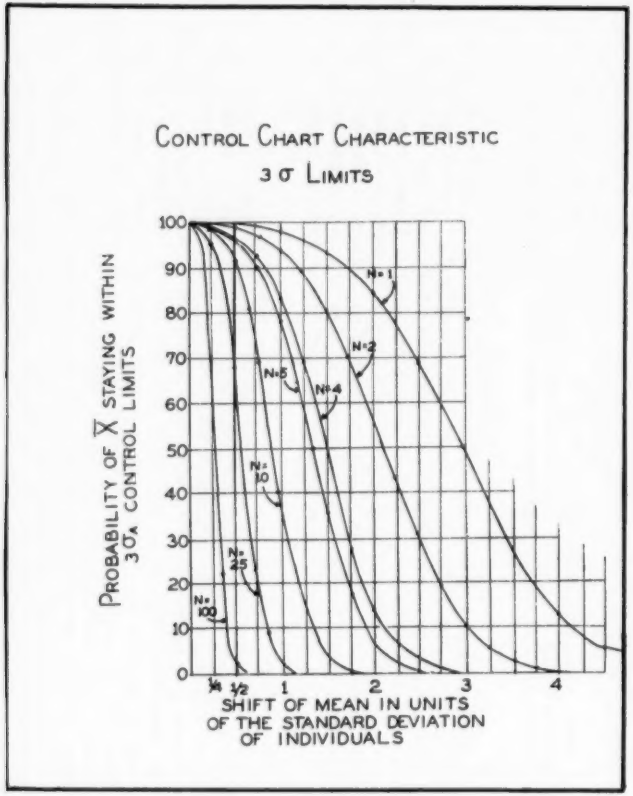
The following material is an approach to these questions. It is not offered as a packaged solution or even as a suggestion or an authoritative point of view. It is an approach that I hope will stimulate critical discussion.

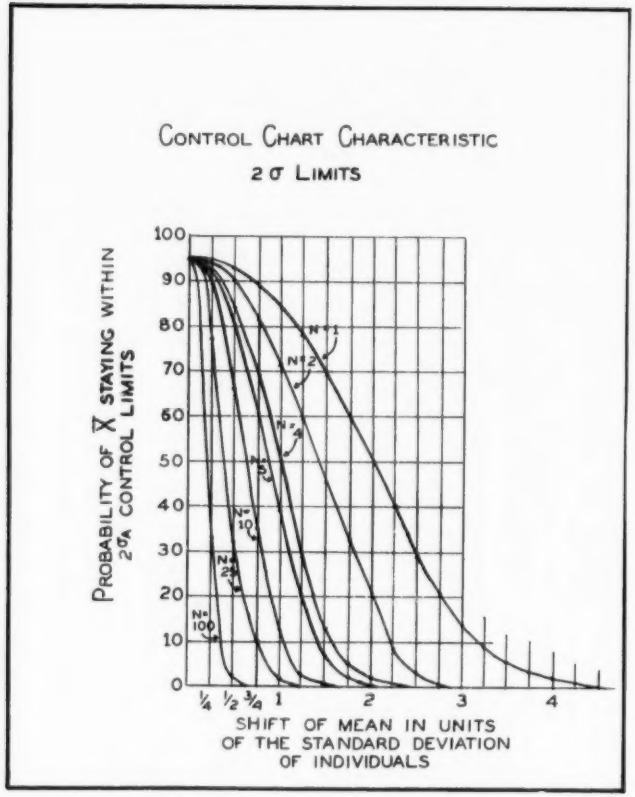
How To Control The Average Fill At The Desired Level

Assuming for the moment that the desired level has been determined through some arbitrary or statistical means, the conventional approach has been to apply $\bar{X}$ charts using 3σ control limits determined through use of the A_2 $\bar{R}$ value. Similarly, conventional sample sizes of 4, 5 or 10 have been selected consecutively from the package stream as the basis for estimating $\bar{X}$ and R. Using this procedure, filler adjustments are made in the appropriate direction whenever a point falls outside the control limits.

In many cases, this program has been remarkably successful in providing a basis for filler adjustment and reducing fill variations that would otherwise have occurred. In other cases the range has indicated satisfactory control but $\bar{X}$ points outside of control limits occurred frequently due to instability of the mean points with respect to the control limits. Increased sampling - and consequent adjustment - frequency has been only a partial answer for if sampling cost did not become excessive the physical ability to select, measure, and adjust rapidly became the limiting factor.

When this variation of the mean becomes so rapid that it might be termed a flutter rather than a fluctuation, there appear to be only two courses of action. The preferred approach, of course, is to determine the cause and remove it. The alternate approach is to accept the flutter as an uncontrollable source of variation and change the sampling procedure to include its effect. This can be done by taking a stratified sample over a longer period of time than that represented by consecutive packages. For example; change from 5 consecutive packages to every 50th package until 5 have been selected. Care should be taken, of course, not to select a multiple of the number of filler heads. This procedure will increase $\bar{R}$ and as a result, will widen the control limits. When and if the cause of the flutter is corrected, $\bar{R}$ will return to its previous


CONTROL CHART CHARACTERISTIC
3 σ LIMITS
PROBABILITY OF $\bar{X}$ STAYING WITHIN $3\sigma_{\bar{X}}$ CONTROL LIMITS
100
90
80
70
60
50
40
30
20
10
0
N=1
N=2
N=3
N=4
N=5
N=10
N=25
N=100
1/8 1/2 1 2 3 4
SHIFT OF MEAN IN UNITS
OF THE STANDARD DEVIATION
OF INDIVIDUALS


CONTROL CHART CHARACTERISTIC
2 σ LIMITS
PROBABILITY OF $\bar{X}$ STAYING WITHIN $2\sigma_{\bar{X}}$ CONTROL LIMITS
100
90
80
70
60
50
40
30
20
10
0
N=1
N=2
N=3
N=4
N=5
N=10
N=25
N=100
1/4 1/2 3/4 1 2 3 4
SHIFT OF MEAN IN UNITS
OF THE STANDARD DEVIATION
OF INDIVIDUALS

value.

Food packers who have gone to the effort of setting up control charts and conscientiously make an appropriate adjustment when an out of control limit point occurs occasionally assume that the standard deviation of the output is essentially the same as the standard deviation determined from the range. This is not necessarily true. For example; assume that $\bar{R}$ for a sample size n=5 has been established as 2.3 (the method of selecting the sample is not involved at this stage). Using the appropriate A_2 and d_2 factors, we arrive at the following terms.

1. Standard deviation of individuals = filler capability = $\sigma_c = 1.00$
2. Standard deviation of averages = $\sigma_{\bar{x}} = .44$
3. Control limits for $\bar{X} \pm 3\sigma_{\bar{x}} = \bar{X} \pm 1.33$

The Quality Control supervisor who has an independent random sampling made of the warehouse is sometimes alarmed to find values for the standard deviation of individual σ_c 1.5 to 3 times those calculated from the range. Among the factors he may suspect are two that may be easily overlooked. One is the fluttering or fluctuating mean mentioned previously. The second is the effect of pooling the output of multiple measuring devices. Their effect is similar. Examination of the operating characteristic of the control chart may be worthwhile at this point.

The control chart limits are primarily designed to detect periods when the apparent change in the mean of the sample is so great that it cannot reasonably be considered to have come from a population centered at the desired average. By constructing the characteristic we can evaluate the probability of a change in the mean occurring without detection. See figures 1 and 2.

Using our previous example for n = 5, $\sigma_c = \pm 1.00$; $3\sigma_{\bar{x}} = 1.33\ \sigma_c$.

We can see that if the population mean shifts + 1.33 σ_c it will coincide with the upper control limit and 50% of the values for $\bar{X}$ will continue to fall within the established control limits. It is not until the shift amounts to 2.66 σ_c that the probability of detection on the first sample after the shift approaches certainty.

It appears evident that when faced with an unstable mean or the problem of adjusting several independent fillers to the same mean, we must take into account our ability to determine when an adjustment is desirable. In this connection Harrison (1) has found that the tendency of package fill to vary in a manner that destroys the independence of individual values such as would occur with a varying mean may be appreciable under some circumstances. He estimates the effect as being equivalent to a shift of 1.4 standard deviations in the average weight of the shipping unit. We can estimate the effect of this weakness by considering it an independent source of variation.

The Relationship

$\sigma_T^2 = \sigma_c^2 + \frac{a}{\sqrt{n}}\ \sigma_c^2$ can be used for this purpose.

Where σ_T is the standard deviation of the total effect of σ_c and $\frac{a}{\sqrt{n}}\ \sigma_c$ and a = the amount of shift of the mean corresponding to a given

probability that the mean of a sample of size n will fail to fall within the control limits. For P = .997 (3σ) a = 6

$$P = .95 \ (2\sigma) \ a = 4$$

Again using the values from our previous examples:

$$\sigma_T^2 = (\sigma_c)^2 + \frac{6}{\sqrt{5}} (\sigma_c)^2$$

$$\sigma_T = 1.92 \ \sigma_c$$

Values of σ_T for other sample sizes are as follows.

	σ_T	
n	3σ limits (a = 6)	2σ limits (a = 4)
1	2.65 σ_I	2.24 σ_I
2	2.29 σ_I	1.95 σ_I
4	2.00 σ_I	1.73 σ_I
5	1.92 σ_I	1.67 σ_I
9	1.73 σ_I	1.53 σ_I
100	1.26 σ_I	1.18 σ_I

As a practical matter, actual performance may be somewhat better if the process is stable or easily adjusted. It may be poorer if control is poor or if sampling is infrequent or adjustments are not made when called for.

The comparatively small improvement as the sample size is increased from 2 to 9 should serve to emphasize the desirability of:

1. Striking at the basic trouble - the cause of instability.
2. Maintaining an independent check on Actual σ_T.

The Desirable Average

As indicated previously, the lower limit on package fill is established by law.

In the United States the food packer has two options:

1. He may stipulate that the label quantity is a minimum. The Regulations (Section 1.8) of the Federal Food, Drug, and Cosmetic Act contain this provision.

> (j) Where the statement expresses the minimum quantity, no variation below the stated minimum shall be permitted except variations below the stated weight or measure caused by ordinary and customary exposure, after the food is introduced into interstate commerce, to conditions which normally occur in good distribution practice and which unavoidably result in decreased weight or measure. Variations above the stated minimum shall not be unreasonably large.

In Canada, the corresponding statement is: ". . . . . where the contents of a package of food are expressed in terms of minimum

weight, measure, or number, the contents of the package shall not be less than the minimum expressed." (Regulation B.01.020)

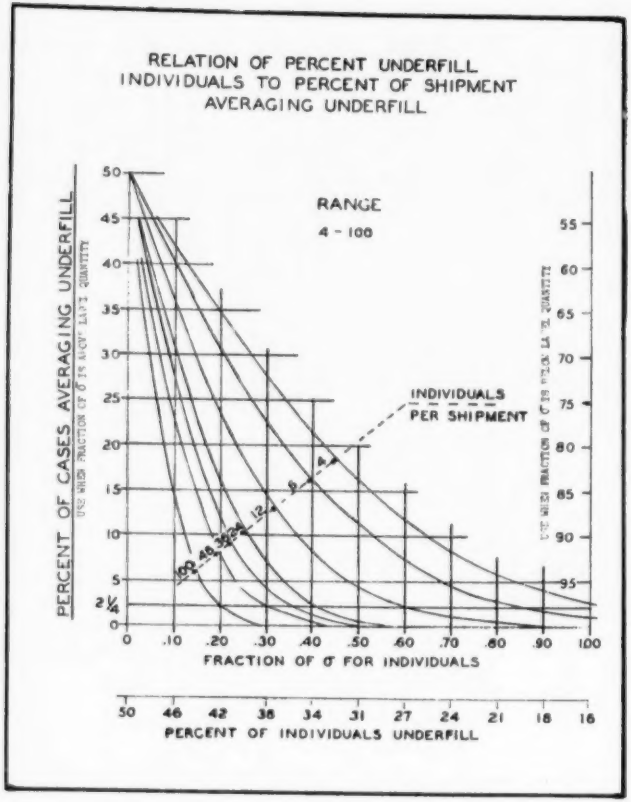
2. He may pack to an average of not less than label statement if gross under fill is avoided.

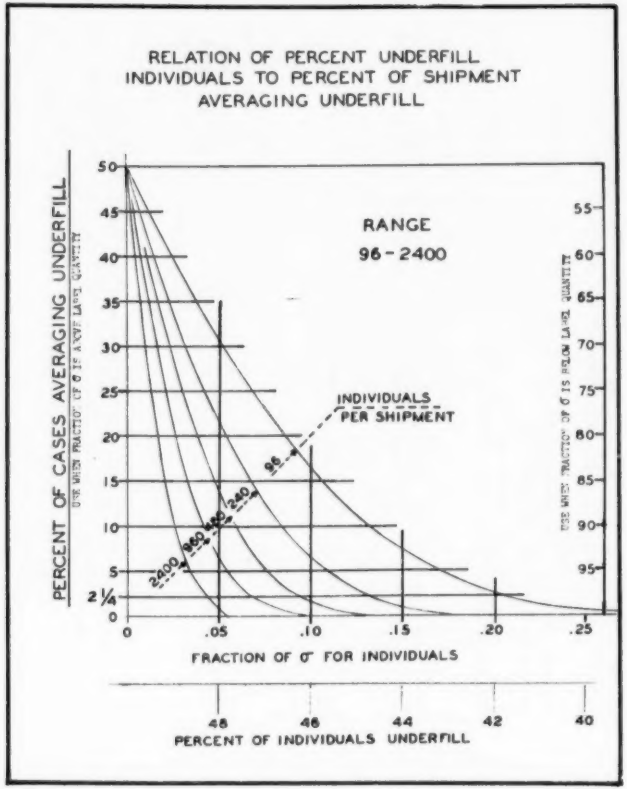
Federal Food, Drug, and Cosmetic Act Regulation (Section 1.8).

> "(i) . . . . . if the statement is not so qualified as to show definitely that the quantity expressed is the minimum quantity, the statement shall be considered to express the average quantity."
>
> "(k) Where the statement does not express the minimum quantity:
>
> > (1) variations from the stated weight or measure shall be permitted when caused by ordinary and customary exposure, after the food is introduced into interstate commerce, to conditions which normally occur in good distribution practice and which unavoidably result in a change of weight or measure;
> >
> > (2) variations from the stated weight, measure, or numerical count shall be permitted when caused by unavoidable deviations in weighing, measuring, or counting individual packages which occur in good packing practice.
> >
> > But under subparagraph (2) of this paragraph variations shall not be permitted to such extent that the average of the quantities in the packages comprising a shipment or other delivery of the food is below the quantity stated, and no unreasonable shortage in any package shall be permitted, even though overages in other packages in the same shipment or delivery compensate for such shortage."

In Canada, the corresponding statement is ". . . . . where the contents of a package of food are expressed in terms of weight, measure, or number, no variations from the quantity declared on the label are permitted other than the following

> (a) variations due exclusively to weighing, measuring, or counting that occur in packaging conducted in accordance with good commercial practice, but not to be such that the average content is less than the quantity declared on the label, as determined by the official method.
>
> (b) variations due exclusively to differences in the capacity of containers resulting solely from unavoidable difficulties in manufacturing, but no greater variation is permitted because of the design of the containers than is permitted in the case of containers of similar capacity that can be manufactured so as to be of approximately uniform capacity and
>
> (c) variations in weight or measure that unavoidably result


RELATION OF PERCENT UNDERFILL
INDIVIDUALS TO PERCENT OF SHIPMENT
AVERAGING UNDERFILL
RANGE
4 - 100
INDIVIDUALS
PER SHIPMENT
PERCENT OF CASES AVERAGING UNDERFILL
FRACTION OF σ FOR INDIVIDUALS
PERCENT OF INDIVIDUALS UNDERFILL


RELATION OF PERCENT UNDERFILL
INDIVIDUALS TO PERCENT OF SHIPMENT
AVERAGING UNDERFILL
RANGE
96 - 2400
INDIVIDUALS
PER SHIPMENT
PERCENT OF CASES AVERAGING UNDERFILL
FRACTION OF σ FOR INDIVIDUALS
PERCENT OF INDIVIDUALS UNDERFILL

> from the ordinary and customary exposure of the package to evaporation or to the absorbtion of water under normal atmospheric conditions. (Regulation B.01.019)

When the packer exercises Option 1 and labels the package as filled to "not less than" a specific amount, it would appear that the average should be established as $3\sigma_T$ above the specification. This is not entirely satisfactory for there is always some residual possibility of an underfill even if the average is set at 4 or 5 σ above specification. In the absence of a legal definition, with regard to how great a percentage of the package may fall into this residual underfill group, the packer, it appears, must establish his own policy.

When a packer elects Option 2 he is confronted with the problem of filling at an average package fill that will give a negligible legal and moral risk of underfill without the economic loss of excessive overfill. Leaving aside the questions of "Good Commercial Practice" and "Gross Underfill", lets examine one possible approach to determining the average.

A "shipment or delivery" may be considered a sample from the population represented by the package stream, having a standard deviation of σ_I. The mean value of a shipment will have a standard deviation of $\sigma_I/\sqrt{N}$ where N is the number of individual packages in the shipment. The average fill for the shipment can be established as:

$$\text{Average} = LN + \frac{t\sigma}{\sqrt{N}} \quad \text{(Where L is the label quantity.)}$$

Under this circumstance when t = 0 the mean $\bar{X}$ coincides with the label quantity and 50 percent of the shipments will have means less than stipulated. When t = 3, only 0.13 percent (essentially zero) of the means will be less than stipulated.

The mean fill for individual packages can be calculated as:

$$X = \frac{LN + \frac{t\sigma_I}{\sqrt{N}}}{N} = L + \frac{t\sigma_I}{N\sqrt{N}}$$ Figures 3 and 4 were developed in this way.

These curves are directly useful when the standard deviation σ_T of the overall process is equal to the standard deviation σ_I estimated from $\bar{R}$. It is also directly useful when $\sigma_T > \sigma_I$ if the units composing the shipment can be considered random selections from the overall process. σ_T can be used in this situation. Conditions favorable to this situation occur when

(a) A number of dependent fillers contribute to each shipment,
(b) Some form of scrambling and mixing is part of the process.

When these conditions do not exist, the shipment to shipment variation is a function of machine capability σ_c and the variation of the mean σ_M. From a Weights and Measures point of view, these values cannot safely be considered as following the square root law and must be considered additive. The target for individual units then becomes:

$$\bar{X} = L + \frac{t\,\sigma_c}{N\sqrt{N}} + t\,\sigma_m$$

Where the standard deviation of the mean can be estimated as $\sigma_m = \sigma_T 2 - \sigma_c 2$. I would be the first to agree with anyone who points out that use of the $t\,\sigma_m$ term without in some way recognizing the influence of N may be costly. It is probably true that carload shipments

of 2,000 - 100,000 units are less likely to experience as group the effect of t σ_m than are smaller shipments of 1, 2, or a dozen units. Use of the unmodified term is mentioned here because used in the absence of evidence to the contrary, it will give greater assurance of meeting legal requirements and at the same time, create an economic incentive for reducing σ_m.

There remains the question of how many units should be considered a shipment.

There are several ways of establishing the shipment quantity. The legal limitations apply equally to shipments of all sizes, however, it is generally impractical to adjust the mean for each shipment. The smallest quantity likely to be shipped as a unit is the most obvious yard stick. Analysis of actual shipments may indicate that 98 percent of the shipments are 100 pieces or more. If 100 pieces are used as the criteria the risk will be greater for the 2 percent that are smaller and less for those larger.

Another rational basis would be to select the smallest shipping unit such as one case of perhaps 12 or 24 pieces. However, when the selection of the shipment size is made you will wish to do so in such a way that the risks and costs can be estimated.

In summary, what have we been trying to say? It is this:

Use the control chart to check and adjust your fillers but maintain a supervisory spot check and analysis to estimate total variation. When a variable mean is operating, control chart control of a filler may result in an actual standard deviation of individuals twice as large as anticipated by the control chart.

The square root law can be used to estimate the variation in shipment averages and to set the target value, however, the component of variations due to fluctuation of the mean must be added to this value in order to be on the safe side.

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STATISTICAL COST CONTROL AND ANALYSIS

Ervin E. Schiesel
The Mattatuck Manufacturing Company

The determination of costs, productivity and departmental efficiency and its control can be accomplished readily and with a minimum of paperwork by applying the principles of statistical quality control. The advantages of statistical control applications over conventional cost accounting procedures is the rapid calculation of results so that a day to day check on performance can be readily made. Control methods provide a means of analyzing production to determine short and long term trends, cycles, and inherent variations from a norm, all of which are not possible with static accounting concepts in operation today. The philosophy underlying this analysis deals with the constant system of causes, assignable causes of variation by means of control charts, and other elements of statistical quality control that have been used so successfully in the inspection and manufacturing fields.

Statistical methods need not be endless rows of figures and complicated mathematical formulas for the determination of averages, trends and limits, because in the use of control chart techniques, the information can be obtained by means of small sample readings which are illustrative of the whole picture. In applying the Shewhart concepts to managerial control, it is necessary that a sensitive and significant variable be selected as the cost indicator of how a department functions in relation to the environment of the plant, and how it is affected by internal changes, as well. In the operation of any manufacturing enterprise, there are many variables that have a constant effect on the productive efforts of the labor force and variations from an arbitrary norm may be random chance or due to assignable causes. The accounting approach deals with all variances as symbolic. The statistical control theory deals with only those which are assignable causes. This partially explains why there is less need for endless paperwork and calculations so necessarily associated with the accounting field.

The example used in this paper is from a plant which assembles its products on a straight line basis with a supervisor in charge whose duty it is to coordinate the efforts of the group in producing a scheduled number of units with an amount of labor ascertained from comparative method and cost studies. These lines were set up as a result of a detailed study of the operations involved and a balance of these operations to each other, rather than to a "standard" established by stopwatch and leveling factors.

This progression of methods and time study analysis has been covered by the author in talks before the American Society for Quality Control and other groups, but has not been published, as yet. In this approach, only raw data is used and is not leveled. The same criteria for stability of the universe and constant system of chance variation is used in determining the productivity level of a single operator and the relationship to other operators and production output.

This has made for a dynamic study in relation to daily production, the top limit of which was fixed by the output of parts

from other departments. When an equilibrium was reached between the supply of parts and the capacity of the line, productivity improvements could be made only in eliminating bottlenecks by further method studies. The internal, as well as the external, changes in production were known to all concerned in the plant, from the assembly worker on up, but a quantitative measure in terms of cost or foreman participation in effecting the changes had not been accomplished by the supervision. As the assembly labor was roughly one-third of the total cost of production, it was important to keep a close check on the labor input and product output, in order to bring about a realistic pricing based on actual expenditures.

Any statistical method that is to be valid should be based on a sufficient amount of data to give a verifiable indication of the situation under consideration. The data used to illustrate this method was taken from an assembly line that was operating at capacity for the entire period of study. The method of taking the data, as well as its evaluation, will be described in chronological order prior to the discussion of the results.

The department to which this control chart method was applied-assembled, tested, and completely packed a product (made up of two molded plastic parts, seven metal and fibre stampings and sub-assemblies.) Actually, the production facility was made up of two separate lines, one of which had less refined jigs and fixtures than the other, and which was originally installed as a temporary expedient requisite with the increase of supplied parts. Production on the line had stabilized, and the number of people necessary to achieve this output was fixed. The foremen of the line managed to achieve the daily output with zero to four absentees, and the performance of the department was judged merely on the basis of the production totals for the day or week.

With a minimum of reports and subsequent work load in their fulfillment, the following method was utilized to collect the data necessary for the study:

At the end of each day's activities, the number of workers on the line, the time spent by each, and the total production was submitted to the Personnel Department which calculated the number of man-hours expended on the line, and the index number which is the quotient of the total number of man-hours divided by the total production in thousands. All cost data used was based on price per thousand units of manufacture. However, the reason for using the index number, rather than the actual cost, is that the hourly labor rates are subject to change, and the problem is not primarily one of measuring costs, (by which the accountant is guided,) but rather the effectiveness of labor expended on the line and its control. The index serves as a basis by which costs can be ascertained in one simple calculation, creating a constant measure of productivity, regardless of the wage structure. These daily indices were plotted as slanted lines on the chart of daily productivity.

The results of the first month's indices were plotted against time and examined for what might be termed "significant trends." It could readily be seen that a correlation existed between pro-

ductivity and the indices plotted during the first month of data. This was due to the absenteeism fluctuation factor throughout the week, the maximum absenteeism rate occurring at the first part of the week, causing the high index figure; whereas the better attendance at the end of the week made for lower productivity per man hour. This became a part of the constant cause system that was inherent in the plant, as well as in the department under observation. The summation of all these constant causes resulted in the average index and variation about this mean.

It was possible to isolate these inherent variations from those caused by outside influences in the application of the principles of Shewhart control charts for variables. The envelope or limits between which these indices fell were wide enough to allow for these "natural" fluctuations, but narrow enough to indicate the presence of assignable causes of variation. However, the sensing is possible only in the use of averages of appropriate subgroups. In this case, it was found that averages of two successive days from Monday to Friday proved to be the most sensitive indicator of productivity.

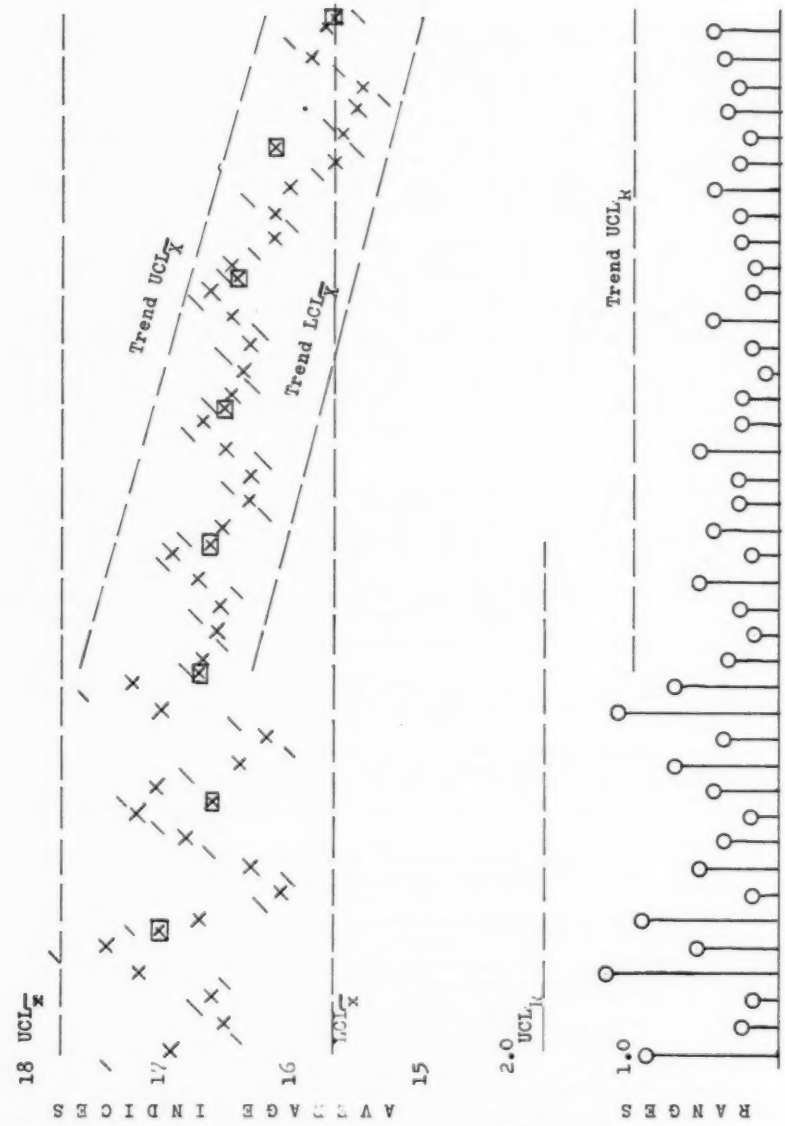
The points plotted as "x" on the control chart were successive daily averages during each week of operation, as well as the ranges which comprised the differences between the indices of two successive days. In addition, the weekly averages were computed by dividing the total weekly man hours by the total production in thousands. This determined the actual cost of the week's production, and when plotted, aided in eliminating the cyclical variations and determining the long term trend.

For the remainder of the discussion, statistical quality control terminology shall be used as follows:

x	Daily index number - man hours divided by number of thousands produced.
$\bar{X}$	Average of two successive days' index numbers.
$\bar{\bar{X}}$	Grand mean index number - total man hours divided by total thousands produced.
$\boxed{x}$	Weekly averages of the indices.
R	Range - difference between successive days' index numbers.
$\bar{R}$	Average range - average of the ranges for the period under observation.

The grand average mean for the first month was calculated but not drawn in the control chart for averages. The control limits for the averages and ranges were calculated on the basis of the average range of sub-groups of two with the aid of the A_2 D_3 and D_4 factors from the American War Standards Z1.2. of 1942, and drawn in on the charts.

After examination of the charts with the superimposed control limits, it can be seen that all of the points lie within these



KEY
/ Daily Index - Man Hours Per Thousand Pieces
x Average of Two Successive Daily Indices
o Range of Two Successive Daily Indices
[x] Average of Indices for the Week

FIRST AND SECOND MONTH OF LINE OPERATION

control limits. This, in no way, suggested that the process was operating at optimum efficiency, or that it could not be improved, but rather that it behaved as a stable universe with fluctuations between natural limits of variability inherent in the cause system.

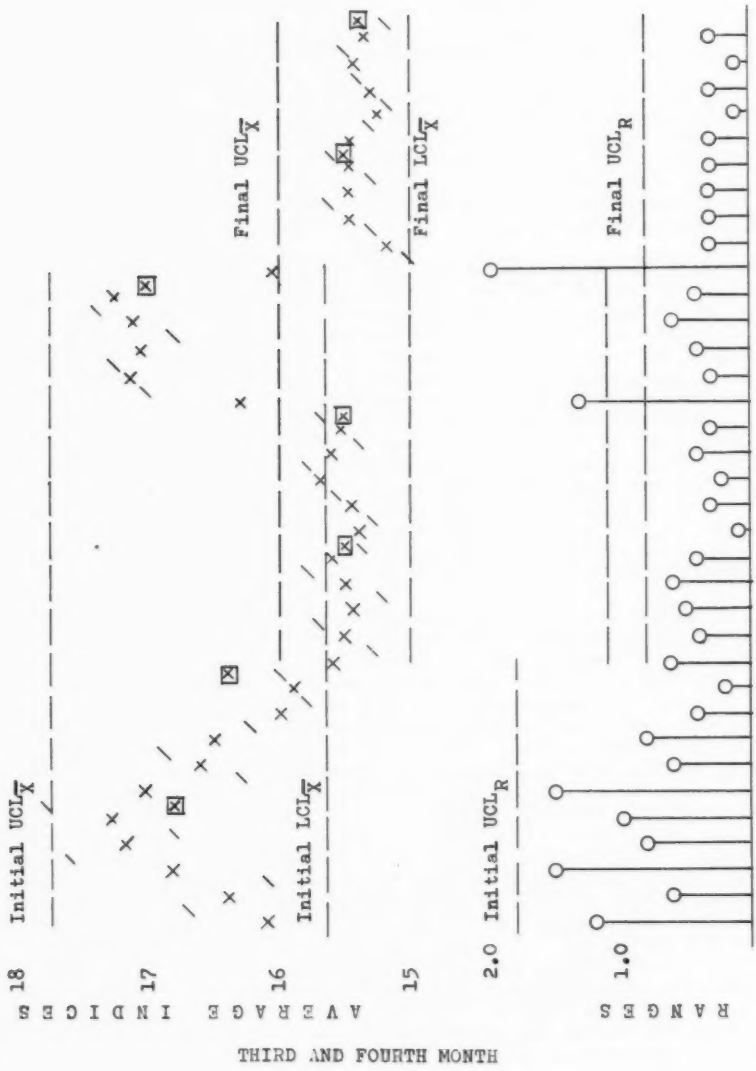
With reasonable assurance that the differences in productive output was due to a constant system of chance, rather than assignable causes, it was assumed that a change in the method of the operating line might show changes beyond the original universe. By regrouping of all the operators into one line, and the elimination of two bottleneck operations by more mechanized equipment, the second line was abandoned.

After a few days of instability, as shown on the charts, the foreman of the department was introduced to the charting method, and an active interest in the productivity relationship to the method changes was indicated. It was felt that the increase in output was due in part to this interest and conscientious effort to make a showing, as well as the actual method shuffles. At the end of the next two weeks, it was evident that the average level had changed, because eight points in a row were below the average established in the first month. The chart was continued without extending the limits about the mean index, because of the possibility that the stable universe was now a steadily changing one with limits parallel to a trend line. This is a reasonable assumption because the variations that made up spread of productivity were still inherent in the operation of the plant, even though the productivity was on the increase.

During the end of the second month, there was a sudden shift in the course of the averages, which was due to the lowering of the quality of incoming parts. It was interesting to note that these averages would have been inside control limits based on the first month's operations, but with the change of the cause system, this lowering of input quality became an outside influence, rather than a part of the system. Thus, the control chart was able to indicate trouble due to a change of incoming materials used, as well as a change in methods, as shown by the sudden increase in the indices' reference averages.

During the end of the third month, it was necessary to utilize both lines temporarily because of plantwide adjustment of personnel. These averages, again, were within the old control limits, but were decidedly away from the downward trend that the process had exhibited. The line for the weekly averages showed the actual productivity and the trend. The lowering of the index proceeded for the following month at a decreasing rate until a stable universe was reached, and a condition similar to that exhibited at the outset was experienced, but with a much smaller range and consequently narrower index limits.

This method of control can be applied to a particular department and an evaluation of work output and effort input relationships can be made, providing the proper grouping and resultant sensitivity actually shows what is happening. There is no shortcut method of doing this, and a thorough study of the characteristics of the departments must be made in order to accomplish changes and, likewise, reflect these in the charts. It is import-



ant that it should not be used alone, or as a lever to increase productivity without accepting the responsibilities that bring about more efficient use of manpower, machinery and materials.

REFLEXIONS SUR LE QUALITY CONTROL

Gaston Fournier

The Acton Rubber Limited

Il y a environ une dizaine d'années nous avions le privilège de prendre contact pour la première fois avec l'outil formidable que nous appelons le Quality Control. A cette époque cet outil était offert à l'industrie sans instruction précise sur la façon de s'en servir. Les opinions sur l'efficacité de ces méthodes étaient alors partagées. S'il est vrai que quelques pionniers avaient déjà obtenu avec l'aide de ce système des résultats très éclatants, d'autres n'avaient pas pu en tirer suffisamment de profit, pour justifier les dépenses nécessitées par leur application. Nous devons admettre que dans notre cas, ce n'est qu'après de nombreuses tentatives plus ou moins fructueuses, que nous sommes parvenus à prouver à la direction de notre usine, d'une façon non équivoque, la valeur du Quality Control comme instrument de contrôle pour les excès de toutes sortes.

Une de nos principales erreurs du début a été de croire, comme plusieurs, qu'une connaissance approfondie des mathématiques statistiques était à elle seule suffisante, pour assurer le succès d'un programme d'applications du Quality Control. Nous n'avons pas tardé à réaliser que les études statistiques et les chartes de controles tiraient leur efficacité surtout du fait qu'elles facilitaient l'application de principes de psychologie industrielle, seuls capables de produire les résultats désirés.

Le Quality Control n'est-il pas une méthode de pensée dont le but est d'établir clairement, avec le moins de chance possible d'erreurs, une frontière entre ce qui est bon et ce qui est mauvais. Le Quality Control nous enseigne qu'en dépit de toute la perfection de l'outillage de production moderne, il est impossible d'obtenir une série d'articles parfaitement identiques. Il est donc pratiquement impossible de rencontrer un standard défini, c'est-à-dire sans allocation au dessus et au dessous et lorsqu'il s'agit de contrôler une production nous devons penser en termes de zones de controles plutôt qu'à un standard précis pratiquement impossible à rencontrer.

Pourquoi les choses varient-elles ainsi? C'est parce que les hommes, les machines et les matériaux varient. Les opérateurs diffèrent les uns des autres suivant leur façon de travailler ou suivant l'intérêt qu'ils apportent à leur ouvrage. Le rendement de chaque opérateur varie d'une heure à l'autre, au cours de la journée et au cours de la semaine, à cause de la fatigue ou de la monotonie qu'engendre la répétition des mêmes opérations. De plus des machines de construction semblable donnent des produits légèrement différents. Le rendement de chaque machine peut varier suivant l'usure, les changements de température, le réglage

par les opérateurs et bien d'autres facteurs plus ou moins controlables. La matière première varie d'une série à l'autre, d'un lot à un autre lot, d'une pièce à l'autre. Tout contremaître ou surveillant qui reconnaît ces limitations et qui pense en termes de limites supérieures et inférieures de contrôle, plutôt qu'en termes de standards fixes, applique le Quality Control.

Le problème du Quality Control est d'abord et avant tout un problème de communications. Il s'agit de créer dans l'usine un enthousiasme pour le produit bien fait. Ceci est devenu très difficile à cause des méthodes de productions modernes qui ont enlevé à l'ouvrier la plupart des raisons qui autrefois auraient pu provoquer un tel enthousiasme. L'artisan est maintenant disparu de nos usines et chaque opérateur est réduit à exécuter une série de mouvements sur une ou plusieurs parties d'un article que souvent il ne voit même pas une fois terminé. L'ouvrier d'aujourd'hui n'a donc pas conscience d'être l'auteur d'un produit qui porte sa signature et dont il peut s'enorgueillir. L'expérience a de plus démontré que les cadeaux en argent ou les blâmes se sont avérés très inefficaces comme moyens de susciter cet enthousiasme.

La complexité des méthodes de productions modernes a de plus rendu nécessaires une multitide d'observations sur tout produit pendant et après sa fabrication. Avant l'avènement du Quality Control les résultats de ces observations étaient compilés dans des rapports périodiques, écrits à l'intention de la direction, dans le but principal de mettre en évidence les responsables des défaillances dans le contrôle de la Qualité.

Si l'on considère la quantité énorme de data nécessaire pour suivre la marche d'une usine moderne, et que l'on admet que chaque chiffre sur un rapport ne prend du sens qu'en autant qu'il est comparé aux autres résultats sur le même item dans des rapports précédents, on se rend compte qu'il est devenu impossible ou du moins très difficile, à un contremaître ou même à un gérant, de pouvoir interpréter correctement les rapports nombreux qui s'accumulent sur son bureau. Il ne faut donc pas être surpris si à plusieurs reprises des actions injustifiées ont été prises au cours de soi-disant campagnes de qualité, dont le but était de corriger des excès qu'une étude statistique aurait interprétés comme étant plutôt de simples variations incontrolables, inhérentes au procédé lui-même. La psychologie moderne nous révèle que le dommage que peut produire l'oubli d'une critique justifiée, est bien inférieur au dommage causé par une critique injustifiée.

Le Quality Control en rendant l'interprétation de ces rapports une affaire de routine, ne pouvait manquer de produire des résultats formidables. Nous avons retiré des mains de la supervision tout le data qui lui était fourni, souvent bien plus pour l'ennuyer que pour le renseigner.

Nous avons établi des limites de controles pour chacun des items montrés sur ces rapports. Nous avons fourni à la direction un rapport digéré donnant seulement les items hors des limites de controles.

Après avoir pratiquement éliminé toute action injustifiée de la part de la supervision, il fallait maintenant diriger vers les vrais responsables de la qualité, c'est-à-dire les opérateurs, l'informatbn accumulée au cours des inspections faites sur le produit, aux différents stages de sa fabrication et à l'inspection finale. Nous avons donc érigé en principe, que toute inspection ne pouvait être justifiée, que si les résultats étaient rendus disponibles pour l'opérateur immédiatement, ou le plus tôt possible, après que les inspections ont été complétées et que ces résultats devaient être interprétés d'une façon non équivoque comme bons ou mauvais, et présentés aux opérateurs de façon à mettre en évidence les bons résultats aussi bien que les défaillances. A cet effet nous avons dessiné une charte de controle standard avec zones de controles, un code de couleur permettant aux opérateurs de discerner entre les zones sous-controle et hors-controle.

Cette attitude que nous venons de décrire, a produit dans deux usines différentes sous notre controle les mêmes résultats, à savoir, une réduction de 75% dans les seconds. Ce résultat a de plus été obtenu, tout en réduisant le travail clérical de compilation des rapports d'au moins 10%.

Etant donné qu'une démonstration de cet aspect du "Quality Control" peut se faire facilement dans toute usine, tout en utilisant les facilités de controle déjà existantes, nous suggérons aux nouveaux venus dans le métier, de faire usage de démonstrations semblables, pour vaincre la résistance des patrons et obtenir leur appui dans l'organisation d'un programme plus élaboré de Quality Control.

Pour notre part, après avoir gagné totalement la confiance de nos patrons, en produisant des résultats fabuleux sans avoir à faire de déboursés, nous n'avons pas eu de difficultés par la suite, à faire valoir l'économie réalisable par le remplacement des inspections à 100% par des systèmes d'échantillonnages à risques calculés, mettant en évidence un autre aspect fondamental du Quality Control en apparence paradoxal, à savoir qu'il est possible en inspectant moins d'inspecter mieux. En effet l'expérience a démontré chez-nous, comme partout ailleurs, que l'inspection continue à 100%, d'une série d'articles, engendre la monotonie qui endort l'attention et réduit considérablement l'efficacité des inspecteurs. Résumant ce qui précède, en introduisant le Quality Control sous sa forme la plus assimilable pour la direction et les employés de l'usine, nous avons ouvert les portes à toutes les autres applications qui se développent de jour en jour, et qui mettent en évidence, l'outil formidable qu'est le Quality Control.

REFLEXIONS ON QUALITY CONTROL

Gaston Fournier

The Acton Rubber Limited

Ten years ago we had the privilege of getting acquainted with this new tool called Quality Control. That tool was then offered to industry without precise instructions on how to use it. The opinions on the efficiency of that tool were very much different among various management circles.

Although a few pioniers had already obtained outstanding results with the help of Quality Control, a few others had failed to derived from it sufficient benefit to warrant the enormous expenditure they had gone into, to apply their Quality Control program.

We must admit that in our case, we had to go through an expensive period of trial and error, before we could demonstrate to management, without the shadow of a doubt, the enormous value of Quality Control as a control instrument for all types of excesses in the factory.

Our first mistake was to believe that proficiency in statistical mathematics was sufficient in itself to assure the success of a Quality Control program. It did not take us long before we realized that statistical methods, and in particular control charts, were efficient inasmuch as they were facilitating the application of powerful principles of industrial psychology.

Is Quality Control not a method of thinking the purpose of which is to establish, with the least chance of error, a boundary between what is good and what is bad. Quality Control teaches us that in spite of the finest production machinery now available, it is impossible to produce a series of articles absolutely identical. It is therefore impossible to meet a precise standard figure, i.e. without allowances above and below, and we must therefore think in terms of zones of control when we establish production control standards.

Why do things vary like that? It is because men, machines and materials vary. Operators differ one from an other by the way they work and also by the amount of interest they put into their jobs. The performance of each operator vary throughout the day and during the week, because of the fatigue and the monotony produced by the continuous repetition of the same operations. Machines similarly built also give products slightly different. The production of each machine will vary due to the amount of wear, temperature changes, set tings by operators and many more or less controlable factors. Raw materials vary from one batch to the other, from lot to lot etc. Every foreman or supervisor that recognizes those limitations and thinks in terms of upper and lower control limits when he sees standards, applies the fundamentals of Quality Control.

The Quality Control problem is a problem of communications. We must create in the factory enthusiasm for a job well done, a product well built. That problem has become increasingly difficult due to our actual production methods which have practically eliminated the craftsman in our factories. Factory workers of to'day do not feel like the authors of the product coming out of the production chains on which they work. Experience has also demonstrated that neither money nor blame could give back to the worker the pride and the enthousiasm required to motivate their interest in the control of quality.

The complexities of our modern production machine have necessitated the accumulation of a tremendous amount of data for the control of quality, keeping cost to a minimum. Before the era of Quality Control, results of factory inspections were compiled in numerous periodical reports written mostly for supervision, often with the main purpose of finding operators to be penalized rather than operators to be helped. Since we must admit that each figure on a report takes a signification inasmuch as it is compared with the figures controling the same item on previous reports, one can realize the impossible job of a foreman or even a manager trying to interpret correctly the several reports piled on his desk daily. We must not therefore be surprised if in the past many unwarranted actions have been taken in so-called quality campaigns, to correct excesses which would have been interpreted as unavoidable variations by an experienced Quality Control operator. Modern industrial psychology has revealed that it is far less disastrous not to criticize when justified than to criticize when not justified.

With the help of Quality Control methods the interpretation of reports has become a matter of routine. In our factory we have withdrawn from the hands of our supervision and management all those reports which were a source of headaches and often a source of mistakes to them. After a careful study of our process we have established control charts for every item shown on those reports. We have replaced same reports by one single digest report showing the items outside control limits only.

Having limited the unjustified intervention of supervision in production control, we have directed towards the true responsible for quality, i.e. the operators, the information gathered in our inspections. We have set as a principle that " the results of each inspection should go to the operators concerned, immediately or very soon after those results have been obtained " and " that same results be interpreted immediately as good or bad." In doing that we were putting just as much emphasis on good performance as on bad performance. Quality Control charts, with colored control zones identified by a color code, have been found indispensable in achieving our results.

The attitude we have just described, has produced in two independent factories a reduction in the percentage of

seconds of 75% based on the best performance ever achieved prior to the application of Quality Control methods. Further more, those results were obtained while reducing by at least 10% the amount of clerical work previously required for the handling of the information obtained in our inspections.

Since a demonstration like the one we have just describe can be quite easily achieved with existing means, we suggest to newcomers in Quality Control to try similar simple demonstrations to overcome the resistance of their bosses to those newer methods.

As a result of the great success obtained in the reduction of seconds by interpreting existing data correctly by means of Quality Control methods, we have gained the entire confidence of our management in Quality Control. We did not have much difficulty selling to our management other Quality Control projects requiring the hiring and training of specialized help. We have applied successfully sampling inspection schemes thus demonstrating to our management one other aspect of Quality Control which may sound paradoxal i.e. "we can inspect more efficiently by reducing the amount of inspection". In fact, experience with sampling inspection in our factory has confirmed that by breaking the monotony inherent to continuous or 100% inspections we can improve considerably the efficiency of the inspectors.

Summarizing, we have tried to introduce Quality Control in our factory by planning simple demonstrations accessible to both management and labor. The success obtained with that procedure has opened the doors of our factory to many other applications of Quality Control requiring more advanced techniques, and therefore harder to sell to management.

QUALITY CONTROL IN EUROPE - PAST, PRESENT, AND FUTURE

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I think I've accepted an impossible assignment: in so short a paper it is obviously not possible to cover in detail either past or present or future of even one country in Europe, much less a whole continent. However, we have here today some twenty representatives from various countries in Europe, and I would like to sketch in broad outlines the European developments, indicate why this group is here, and whet your appetite for information which they can give much better than I.

It has been my good fortune to have had a recent birds-eye picture of the European scene. From September 1954 to September 1955 I served the European Productivity Agency as consultant on Quality Control. From what I learned in this brief period, let me review the past history of Quality Control in Europe. I have no intention of giving a review of statistical theory, and the antecedents of Quality Control go back a long way. I do not want to start with Fermat or Gauss or LaPlace or Tchebycheff. In the United States the reference dates usually taken are 1931, when Shewhart's "Economic Control of Quality of Manufactured Product" was published, and 1933, when the A.S.T.M. "Manual on Presentation of Data" appeared.

For England, a similar reference date might be 1935, when the British Standards Institution published E. S. Pearson's "The Application of Statistical Methods to Industrial Standardization and Quality Control." From 1935 to 1950 publications appeared in practically every language of Europe, and just a list a names is impressive: in England, Tippett, Dudding, Jennet, Barnard, Sealy, Wharton, Desmond and Swan; in Germany, Daeves, Leinweber, Graf and Henning; in Spain, Chacon and Blanco; in Switzerland, Linder; in France, Darmois and Mothes; in the Netherlands, Hamaker and Van Dantzig; in Denmark, Hald. The trouble with such a list is that one could not possibly include all the outstanding contributors, and the foregoing memory sample is offered as evidence of the widespread interest that had been aroused. The conslusion is that throughout Europe there is an elite who are thoroughly familiar with the concepts and techniques of Quality Control.

To what degree has industry accepted these procedures? In 1950 the International Statistical Institute published a booklet "Applications of Statistical Methods to Problems of Production in Industry" which was a digest of the papers presented at the 1949 meeting in Berne. Reports on Quality Control and Industrial Statistics were presented, covering the following countries: Belgium, England, France, Sweden, Switzerland, Spain and Czechoslovakia. In general, the situation was analagous to that in America before the founding of the American Society for Quality Control. There were individual companies and institutions achieving excellent results where an outstanding individual had been able to make progress. However, there was no widespread acceptance of these techniques by European industry. The situation differed greatly from country to country, both as to stage of development and potential needs.

Since 1950 there has been a considerable increase in interest in the subject of Quality Control. There have been at least three separate national teams who have visited the United States with this

specific objective. These teams were from England, France and Denmark. In addition, there has been a steady interchange of experts in this field. Going from the United States to Europe at different times have been such outstanding experts as J. M. Juran, E. H. MacNiece, John W. Enell, W. Edwards Deming, M. E. King, and others. Coming over from Europe to America have been an equal number of distinguished visitors.

In this connection, special mention should be made of the International Statistical Institute. The meetings of this organization have been a constant stimulus to the work in Quality Control. The work of the I.S.I. Committee on Statistics in Industry and Technology, which published the "International Journal of Abstracts on Statistical Methods in Industry" is of utmost importance.

During the period from April 1954 to August 1955, the European Productivity Agency, a division of the Organization for European Economic Cooperation, sponsored a series of projects designed to increase European productivity. Some of these projects were jointly sponsored by the Foreign Operations Administration of the United States government. One such project was E.P.A. Project 148 on Quality Control. I think it is significant that the United States agency sponsoring this activity was called the Foreign Operations Administration at the start of this program and had become the International Cooperation Administration by the end of it.

During the first three months of this project, Professor S. B. Littauer and Dr. A. N. Benson served as consultants for the E.P.A. The writer spent the succeeding year (September 1954-September 1955) in Europe as a consultant on this work. The countries sponsoring the project were: Austria, Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Sweden and Turkey. Supplementary visits were made to England and Yugoslavia. This report on the Quality Control developments in Europe is based on this experience, and of necessity it is to some extent a report on Project 148.

This program, as originally planned, had two major objectives. The first was to present to Industrial Management the functions and objectives of modern quality control. The second objective was the training of industrial personnel. As the program developed, two additional objectives emerged. One was the need for developing teachers and trainers in Quality Control, both at the University level and within industry. Another was the need for channels of communication so that those becoming active in the field would be able to meet and discuss common problems.

To meet these objectives it was originally planned to have a team of two members: one a specialist in the field of applications and management, and the other a specialist in teaching. For the major part of the program this could not be done for economic reasons, and to the extent of his abilities, the writer was asked to combine the role of the two specialists.

Being the only member of such a team has advantages as well as disadvantages. Most of these need not be discussed. However, it was obviously impossible for one person to carry out the desired program unless the cooperation of many European counterparts was secured. A preliminary visit was made to the countries first on the list for implementation. Programs for management meetings, one and two day seminars,

and visits to major industries were established. Plans for future training programs were established, as well as criteria for evaluation of the entire project. As a result of this planning, and program in each country was individually tailored to the needs discovered.

In each country a series of meetings with management were held. In Austria, Norway and Italy, training conferences for industrial personnel were carried out. In Germany and Denmark, two weeks seminars for teachers and trainers were developed. In Belgium, France and the Netherlands the programs were centered about industry divisions such as textiles, machining, etc. Finally, in each country a definite evaluation program was attempted to determine the economic importance of the results achieved. In concluding this brief description of E.P.A. Project 148, I would like to pay tribute to the large group of European experts who played such an important role in making this program a success. In every country they gave freely of their time in planning and carrying out the various parts of the program. It truly was an International Cooperation program.

Surely anyone who has worked in Europe will recognize the tremendous differences in industrial development that exist between different countries. And anyone who has worked in statistics knows well the dangers of generalizations. Despite this it seems to me that certain common needs exist in all countries, differeing only in degree. As I viewed the situation these needs are:

a. There is a need for management education as to the objectives and functions of Quality Control. Problems of allocation of quality responsibility, vendor-purchaser relations and economc design of tolerances need to be better understood. To meet this need many one and two day management conferences were held.

b. There is a need for training of production personnel. In general there exists a good knowledge of statistical theory, but less understanding of the relationship between the statistical, the economic, the technical and the psychological aspects. The viewpoint advanced by Project 148 was that modern Quality Control consists of efficient industrial procedures, with efficiency judged by these four aspects.

c. There is need for cooperation between the statistician and the engineer. Cooperation between these has been a recent development in America, and is just beginning in most countries of Europe. The need for such cooperation was stressed in meetings with University personnel and with Industrial management.

d. There is a shortage of competent trainers in the field. To some extent this is due to the lack of interaction between University and Industry. In some countries special programs for trainers were organized. Unfortunately there was not enough time to carry out similar programs in all countries.

e. Both within and between countries there is need for channels of communication. Organizations devoted to Quality Control are in the embryo stage in each country, and communication between countries is very limited.

Next let me indicate just a few of the recent developments in certain areas. First in Scandinavia. There has been considerable work done in Sweden and Denmark, somewhat less in Norway. Professor Hald in Denmark has a two volume text which is widely used. In addition, many case studies of applications have been mimeographed and circulated in the three countries. In December 1955 the first issue of the Scandinavian Journal of Industrial Statistics was published in Copenhagen. A Society for Quality Control has been formed in Sweden, and similar groups without formal organization exist in Denmark and Norway. Cooperation between the three countries is excellent, with frequent exchange of teaching personnel.

In the Netherlands there is a very active Industrial Section of the Netherlands Statistical Society. In addition there has been created the "Foundation Quality Service for Industry" with joint Government-Industry sponsorship. The Foundation coordinates research in the field of applications, develops industrial programs and training courses for specific industries, and since March 1955 has published a bi-monthly journal - "Sigma." The first text book in the Dutch language has just been published - "Modern Quality Control" by A. H. Schaafsma and F. G. Willemze of the Philips Laboratories. And of course mention should be made of the widely used Philips Standard Sampling System, developed by H. C. Hamaker. This is available in five languages, and it is my understanding that "Modern Quality Control" is being translated into English, German, and French.

In Germany the work in this field is carried on by the Committee on Technical Statistics of the Ausschuss fur Wirtschaftliche Fertigung. Ten local sections of this committee, similar to local sections of A.S.Q.C. are already in existence. The Committee has published several booklets on Statistical Quality Control, and is continuing this work. Arrangements have been initiated for the translation of the A.S.T.M. "Manual on Quality Control of Materials" into German. Walter Masing, vice chairman of the Committee has just published a text, "Statistical Quality Control in the Cotton Spinning Industry."

In France the center of activity is the Institute of Statistics of the University of Paris. Under the direction of Professor Georges Darmois the Institute has initiated a complete program of industrial training in this field. Since 1953 the Institute has published an excellent Quarterly, "Revue de Statistique Appliquee." The work of the Institute has aroused the interest of the engineering fraternity and is beginning to have a widespread effect in industry.

In England so much has been done that it would be rather presumptuous on my part to attempt a summary. During the war developments in the United States and England were comparable. The Ministry of Supply supported an Advisory Service on Quality Control which functioned in much the same manner as the OPRD program in the United States. At the end of the war, when both programs were discontinued, the American Society for Quality Control was formed, but in England no such development took place. The interest of the Royal Statistical Society and similar groups continued, but industrial interest decreased. Late in 1951 a British team on Inspection Methods in Industry visited the United States. Their report, "Inspection in Industry" was released in February 1953. This report spelled out some ten recommendations for British Industry. After considerable study by the various management, professional and technical societies it now appears that the Institute of Engineering Inspections

will expand its functions in the field of Quality Control and may eventually form the nucleus for a Society for Quality Control.

In other countries of Europe the activity has been on a somewhat smaller scale. In Belgium, Austria there are active groups associated with Statistical Societies. The Italian Society for Quality Control has just been formed with a membership of approximately 500. Similar organizations are in the process of formation in most countries in Europe. Thus the present situation in Europe is approximately equivalent to that in the United States at the time of the formation of A.S.Q.C. The natural question is whether an organization similar to the American Society for Quality Control is feasible. There are difficulties of language, custom and unequal industrial development. Despite these difficulties a start has been made.

The E.P.A. sponsored an International Conference in Paris in July, 1955. Thirteen papers were presented by invited speakers from eight countries. The conference was attended by approximately 150 experts from fourteen countries. As compared to the present convention this may not sound impressive. However, the excellence of the food may not always be judged by the size of the menu. The complete proceedings of the conference were published by the O.E.E.C. and are available from them. The results of the conference appear to have been very satisfactory. Contacts between experts in various countries were established, and plans for continued cooperation were made.

Official representatives from each country met at the Paris Conference, and reviewed the present status of quality control in their respective countries. There existed an obvious need for some mechanism to keep these groups in contact with each other, and to study the possibility of establishing a permanent organization to sponsor this activity. To meet this need, the E.P.A. initiated a project (E.P.A. Project 318/3) which provided funds for a Secretariat of an International Committee on Quality Control. Each member country of the O.E.E.C. has been asked to nominate two representatives to serve on this committee. (Canada and America are associate members of the O.E.E.C.) Mr. J. LeCordonner has been appointed Secretary of this committee, and we expect that he will be here today to represent this Committee.

The Committee has just started to function. For its first activity it is planning to publish a booklet "Quality Control in Europe," which is now in preparation. This booklet includes a much more detailed presentation of the work done in Europe than is possible in the present paper. A second function of the committee is to establish a list of organizations interested in the work, and of individual experts in the various countries. Information on this will be available from Mr. LeCordonner, European Productivity Agency, 2 rue Andre Pascal, Paris 16, France.

The objectives of the committee are quite broad, and it will obviously not be possible to accomplish all of them in the immediate future. A statement of the objectives are included in the E.P.A. description of the project, which is given in the appendix.

To help meet the shortage of trainers the E.P.A. and the I.C.A. have jointly sponsored Project 318/2. This project, participated in by some ten European countries has brought an international group of 20 teacher-specialists to the United States for ten weeks. For the past month they

have been visiting plants and educational institutions investigating the problem of industrial training in Quality Control. They are our guests here today and I know they are eager to discuss problems of mutual interest with many of you. I am sure we will do all we can to make their stay a memorable one. I would like to thank the many members of A.S.Q.C. who helped plan this program and who participated so actively in it.

ASQC has always been a society of enthusiasts, and this enthusiasm for Quality Control admits no national boundaries or barriers of customs. The officers and some fifty members contributed back copies of Industrial Quality Control, so that today 25 reasonably complete sets have been deposited in libraries in some 16 countries in Europe. We have individual members in a large number of countried throughout the world. We are actively cooperating with Quality Control Societies in India, Japan and other non-European countries. The Society has just established a Committee on International Cooperation to plan and continue this work. Just as the areas of application of Quality Control continue to increase throughout industry we can look forward to a continued increase throughout the world of procedures to bring the customer standard dependable quality at an economic price.

APPENDIX

Organization for European Economic Co-operation
Productivity and Applied Research Committee
E. P. A. Project No. 318/3
Secretariat for Liaison Between Member Countries
In the Field of Quality Control

Introduction

1. In the second annual programme of the Agency, EPA (54) 81 part I, paragrah 27, the Agency restated its policy of promoting and disseminating managmenet techniques which are not genrally known or applied in Member countries, particularly among small and medium-sized enterprised.

2. Quality control is one of these techniques, and project 148, "Training in Statistical Quality Control", was one of the first projects the Agency undertook to satisfy the need in this field. Conferences and seminars have been conducted in 10 countries; both to inform top management about what benefits can be derived from the application of this technique, and also to train instructors and practitioners within industry in this field. A final report on project 148 is now being circulated under PRA/BA(55) 16.

3. In July of this year, an international conference on Quality Control was arranged in Paris (EPA Project 318/1). At this conference specialists in the field had an opportunity to discuss the results obtained from Project 148, to gather information about experiences and practices in other Member countries and to make personal contacts with their colleagues from those countries.

4. As stated in the final report for Project 148, a more widespread application of Quality Control in industry will depend largely upon the availability of instructors in the field. A project has, therefore, been adopted under EPA(55)48, Project 318/2; to give further training to such instructors in the United States.

5. In addition, at the evaluation meeting of Project 148, which took place in July in connection with the international conference, the participants recommended that some means be found to maintain and to further the contacts between individuals, groups and associations working in the field in Member and associated countries.

6. The Director of the Agency, therefore, proposes to give financial support for a period of one year to a secretariat for liaison between Member countries in the field of Quality Control. This secretariat would assist a group of specialists from Member and associated countries in developing and promoting international co-operation in the sound application of Quality Control.

7. It is envisaged that this group of specialists might eventually lead to the formation of a permanent international body carrying out this task independently of the E. P. A.

Objectives

8. The objective of the project is to facilitate the establishment and maintenance of contacts between national groups or associations and individual specialists in Quality Control and related fields in Member and associated countries. In carrying out its functions, the secretariat would co-ordinate its work with that of international groups and associations in allied fields, such as the International Statistical Institute (I.S.I.), Comite International d'Organization Scientifique (C.I.O.S.) and others, and ensure that the work complies with the policies of the E.P.A.

9. Representatives of the various national groups and associations and independent specialists would form an "International Quality Control Group." The members of this group would be competent specialists in the field, willing to carry out their functions without compensation from the E.P.A.

10. Special attention should be paid by this group to exploring the possibilities of creating an international permanent body to pursue the objectives of this project independently of the E.P.A.

Examination should be made of, e.g., the functions of such a body, its statues, conditions of membership, financing, etc.

With the assistance of the secretariat, the group should also initiate some of the functions which may be expected to be continued by the permanent body, when it comes into existence.

11. Such functions may include the items listed below. This list has been established for illustrative purpose. The group will be free to exclude some or include other items as it sees fit, as well as establish the order of preference.

(a) The exchange of publications in the field of Quality Control between Member countries, and the dissemination of information on publications.

(b) The exchange of information on national activities, such as meetings, training courses, conferences, experts travelling to other countries where they might be made available for work in the field, etc.

(c) The co-ordination of exchange of teaching personnel between countries.

(d) The establishment of a directory of persons engaged in Quality Control, competent to render serive in the field upon request. This directory would facilitate the exchange of personnel between countries.

(e) The development of teaching material in the field in the form of a manual for training of foremen, films and film strips, demonstration gadgets, etc., e.g., for vertical sectors of industry, such as textiles, paper, metal working industry, etc.

(f) Co-operation with E.P.A. Information Service in developing a Question-and-Answer Service.

(g) Assisting the Director of the Agency in the preparation and execution of Project 318/2 "Trainers in Statistical Quality Control in Europe."

(h) Reviewing the draft prior to publication of a report on "Quality Control in Europe" now under publication.

Organization

12. The secretariat should be located in Paris to ensure that its work complies with the policy of the Agency. It should consist of a secretary working on a part-time basis, appointed by the Director for this particular function for a period of one year. The secretary should have a sound knowledge of the theory and application of Quality Control and a good acquaintance with the problems of industrial management. He should further be reasonably acquainted with the existing recognised European authorities in the field of Quality Control.

TOOL PROOFING AS A MEANS OF QUALITY CONTROL

A. S. Billings
Ryan Aeronautical Company

The Ryan Aeronautical Company of San Diego, California conducts business both as a Prime Contractor (to the Air Force, Navy and Army) and as a subcontracting manufacturer of specialized aeronautical products. These latter items are produced for aircraft engine manufacturers and for the Military Services.

Ryan's traditional diversification has projected the company into research, development and manufacture of all three elements of modern flight vehicles; the airframes, the engines to propel them, and the electronic equipment to guide them. These typical items which Ryan produces are:

Afterburner Components
Jet Engine Components
Aircraft
Pilotless Aircraft
Rocket Motors
Aircraft Engine Exhaust Systems
Airframe Components
Metallurgical Engineering
Weapons System
Airborne Electrical Equipment

The Ryan Aeronautical Company produces over 250 different articles which are divided into the various categories listed above. Obviously, to produce this quantity of different items for three branches of the Military Services and thirteen other customers for whom we are subcontractors (each customer has his own Quality Control Standards) presents a major challenge from both a Quality Control and Production standpoint. All of our subcontracting customers use the basic MIL-Q-5923B Specification as a minimum requirement starting point and add their own individual requirements.

In order to maintain a positive control over the maze of requirements necessary to produce finished products acceptable to all concerned, one basic organizational concept must be realized. The Director of Quality Control should report directly to the President. This elementary requirement is in effect in our organization.

As a result of many years of study and trial a very efficient and satisfactory Quality Control organizational set-up has been evolved. The Director of Quality Control has the three major Quality Control activities reporting directly to his office;

Chief Inspector
Material Review
Tooling Inspection

This type of functional control is very satisfactory and produces a substantial cost saving in that it streamlines authority and eliminates

a system of useless reports.

These opening paragraphs are not meant as an advertisement for Ryan, but are placed here for explanatory purposes for those individuals who may not be familiar with this type of operation.

The Tooling Inspection Department is under the direct supervision of a General Supervisor and is staffed by a group of inspectors who comprise 20% of the total of 375 employees in the Quality Control Department. Each major type of manufacturing activity such as airframe, jet components, fabrication, etc. has a Tooling Inspection Supervisor to handle tool inspection in his particular bailiwick.

Each new product (of which there are many) is assigned to a particular Tooling Inspection Supervisor. It is his responsibility to follow development of all tools and procedures during development. The below listed significant points must be watched closely during development of a new product:

(a) Precise mating of parts into assemblies (tool proofing).

(b) Practicability and producibility of fabrication, assembly and inspection tools.

(c) Proper sequential assembly of details to provide for heat treat operations, etc.

(d) Final dimensional accuracy.

(e) Control the pilot run of details to minimize amount of scrap due to functionally incorrect tools.

(f) The tool must hold and index any number of parts consistently the same so that the operation performed on the part is within Engineering print tolerances.

(g) Tools must hold and index parts as fool-proof as possible to eliminate loading errors.

During the development period of a new product the inspection sequences to be used in production are developed and a Production Inspector receives an indoctrination course on the peculiarities of this new item. When a sufficient quantity of acceptable new products have been produced to satisfy Tooling Inspection that the item is ready for production the entire "package" is handed to Production and Production Inspection as a proven product. Tooling Inspection continues to act as a "watchdog" over this item in production and is available as a "trouble-shooter" on tooling problems.

The Tooling Inspection office maintains a complete set of "Master Planning" on each part involved in each respective area so that it can move quickly when action is required, and can make a necessary

planning change through Manufacturing Engineers on the production floor without making a carser of the operation.

Tools which come under the jurisdiction of Tooling Inspection are classified into four (4) catagories as follows:

(1) "SOFT TOOLS"

This group includes templates, router blocks, Hydro form blocks, drop hammer dies, etc. The general Engineering tolerances for the parts produced from these tools is plus or minus .030" or more.

(2) DIES AND FIXTURES

Tools which perform a close tolerance function on a part and must be coordinated with other tools in a family i.e. drill jigs, mill fixtures, lathe fixtures, weld jigs, punch press dies, sub assembly jigs, final assembly jigs, etc.

(3) TOOLS PRODUCED BY OUTSIDE VENDORS

Machine tools and large assembly fixtures are controlled, inspected dimensionally and accepted by Ryan Tooling Inspection at the vendors plant if the program in which the too. is involved is on a priority schedule. Otherwise the tool would be received and inspected in the normal manner.

(4) INSPECTION FIXTURES

These fixtures and gages are all controlled by Ryan Tooling Inspection. The inspection control requirements for the above emanates from the Quality Division in coordination with Manufacturing Engineering, Production Control and Tool Planning. Copies of these requirements and control are of sufficient number so that not only do the "Chiefs" receive them but also the individual "Indians".

In addition to Tooling Inspection's duties of inspecting and proving new tools, a constant tooling vigil is maintained in the Punch Press Department. By visually inspecting each 50th part coming off of each press a close control is maintained over tool performance. A dull or broken punch is discovered before excessive scrap is generated. The tool proofing Inspector stationed in the Punch Press Department is directly responsible for ascertaining that defective dies are reworked and will produce a blueprint part.

The mechanics of tool proofing of parts from presses by the sampling method has proven itself a tremendous cost saving operation with no surrender of quality in any way. In fact, it has increased the volume of parts produced and has resulted in better quality and

less down time on the machines. Quality trend charts compiled in this area are excellent.

Another facet of the duties required of the Tooling Inspection Group is the formulation of positive corrective action when tools are determined as the cause for the rejection of parts. Our system requires that a definite and realistic corrective action statement be placed on a rejection tag before parts in question can be accepted through Materials Review. It is the duty of the applicable Tooling Inspector to furnish this information to the Materials Review Board quickly and accurately so that acceptable parts can be returned to the production line without delay.

A record of all investigations and corrective actions on each specific item is on record in both the Tooling Inspection Office and the Materials Review Office. It is through the medium of this type of control that we have been able to come up with our "Quality Control Trend Charts" which is our basis of positive communication between Production Management and Top Management for our weekly and monthly discussions. Also, with this overall control we are able to supply to our Military or Prime Contractor's Source Inspector accurate and detailed information on any given set of circumstances.

The completed rejection tags contain all of the basic data for the reduction of future discrepancies. A running detailed analysis of this data is conducted by the Quality Control group and is supplied to the other departments in several forms.

The most direct and immediate form consists of Red Caution Cards given directly to the Production Superintendents to highlight major problems.

The most detailed form consists of a monthly Department Responsible Report listing all of the month's rejections, each analyzed, and grouped into their generating departments.

A Summary Report is issued to the local Air Force Quality Control Office every month giving a brief on production, rejection rates, and repeat rejections.

Local weekly reports are dispatched to clarify certain trouble spots as needed.

The broad overall pattern of our production progress is presented to Management and to our Customers in the form of Quality Trend Charts showing a running plot of the production - rejection ratio and a plot of the percent of those rejections which are repetitive.

Our analyzed historical record permits closer bidding by locating and fixing costs and points the way to production processes to be used. Thus we are controlling the long term, short term, the broad and the specific problems inherent in precision mass aircraft production.

However, please bear in mind that, to have a system of this type, it is certainly in order to inform the reader that the key personnel

in the Quality Control Department at Ryan have been associated with this Department for a period of fifteen (15) years. This system of operation can only be obtained by qualified personnel in the overall plan. Without very capable "Indians" there would not be many successful "Chiefs".

It is a privilege to be a small part of this program of the American Society for Quality Control and it is hoped that this effort will convey to you gentlemen that the aircraft quality control personnel are vitally interested in your organization.

CONTROLLING QUALITY OF BONDED STRUCTURE FOR AIRCRAFT

Wallace Hay
Convair-Fort Worth

Aircraft manufacturers for over a decade have been producing bonded panels for structural use in airplanes. The first thermo-setting resins were developed just prior to World War II. During World War II, and late 1940's, these resins were combined with synthetic rubber materials to yield an adhesive which exhibited the high strength characteristic of the cured resin and the resilience and vibration resistance of the rubber. These developments enabled the designers to incorporate metal-to-metal bonded components in aircraft. Initially these panels were used solely in secondary structure where failure of the panel in no way could endanger the aircraft. A comparison of strengths exhibited by metal-to-metal bonds with other conventional construction readily shows their strength advantages. In shear a bonded joint will give 2000 - 4500 psi; a 1/8" rivet per square inch will give 800 psi; and a spot weld per square inch will give 850 psi. In addition to the strength advantage, the load is distributed evenly over the entire area in a bonded panel. Thus stress concentrations leading to fatigue failure are minimized.

In recent years designers have been faced with the problems of high speed flight. The advantages of high strength to weight ratio, reduced air drag, insulation against the high friction heat, as well as increased resistance to sonic vibrations have caused a shift from conventional construction to metal-to-metal and honeycomb bonded panels for even primary structure.

It is true that future speeds and the calculated skin temperatures associated with them are higher than present adhesives can withstand. However adhesive bonded panels will be used for several years hence; and their manufacture will present a definite quality control problem for sometime.

Convair has been bonding flat metal-to-metal secondary structure for many a year. However we found that bonding panels of this nature is a far cry from bonding contoured sandwich panels for primary structure. We were forced to re-educate all personnel involved. New equipment, techniques of manufacturing, and control methods had to be developed to handle the problems involved. Familiarity with bonding relatively non-critical panels made re-education that much more difficult. Certain methods of operation had become almost a habit, and people associated with the program had formed individual impressions and ideas that were very difficult to change. Such things as tolerances on detail parts and bonding tools were the hardest problems to overcome.

Controlling the quality of bonded panels involves the following major points which will be discussed in turn in this paper: (1) Adhesives, (2) Detail Parts, (3) In-Process Control of Manufacturing, (4) Equipment - Tools, Fixtures, Presses, Etc., (5) Control Tests on Finished Assemblies, (6) Statistical Analysis of Test Data.

Raw Material Control: The importance of raw material control cannot be underestimated in the manufacture of bonded panels. Organic adhesives are prone to be the source of variation by their very nature. The organic polymers (phenolic, nitrile, epoxy, etc.) themselves can be controlled only with difficulty, and the adhesive manufacturer in turn can add other degrees of variation very easily in compounding the final product.

Aircraft structural engineers are prone to place much emphasis on the strength of the adhesive in tension, compression or shear. Most all government and industrial control specifications depend to a large extent on the "lap shear" value at a given temperature. These specimens are a standard one-half inch overlap bonded in a standard laboratory type press. The "lap shear" value is considered a satisfactory indication of the quality of the batch or lot of adhesive. Peel is also used by many as a measure of quality. This test is used more widely as a daily control check or process check than as an acceptance test. In the case of adhesives used in sandwich or honeycomb panels, a beam compression test is usually run on a section employing the adhesive in question.

At Convair, we have found that these standard tests on panels bonded under relatively ideal conditions in laboratory presses do not always give us the necessary answers regarding the suitability of the adhesive for bonding all types of panels. Thus we have developed additional tests to indicate what we choose to call the "bonding characteristics" of the adhesive. We also have modified laboratory equipment as much as possible to duplicate production bonding conditions.

We suspected that a certain adhesive formulation could be manufactured batch-wise to consistently meet the Military Specifications and other "strength" specifications and yet each batch have markedly different "bonding characteristics". This fact we have discovered is quite true, especially in the case of adhesives used in honeycomb type panels.

In some cases the peculiarities of construction or design leads to a serious problem involving volatiles. Not only the volatiles that may be formed during cure, but also the volatiles that may be present in the adhesive as received. Even film type adhesives made from supposedly 100% solids material give trouble. Wide overlaps in metal-to-metal type bonds and sandwich type panels using unperforated core are the worry spots.

Some lots of adhesive may give very satisfactory panels, while others may give very unsatisfactory panels; even though all lots show satisfactory lap shear results. This is basically due to the variation in raw materials used in the adhesive manufacture, and the variability in the manufacturing operation.

In order to eliminate this problem, we resorted to the use of an empirical "flow test" requirement in addition to the usual strength tests. The amount of flow desired for metal-to-metal bonding may be very different than that desired for honeycomb type panels.

Usually a high flow tape or adhesive is best for sandwich bonding for this allows for easy removal of volatiles even through the adhesive itself if necessary. In the case of metal-to-metal bonding at high pressure, medium flow is needed in order to prevent bond starvation.

Certain adhesives have almost no flow at all. Some acrylonitrile-phenolic adhesives fall in this class. Relatively small changes in flow here can lead to difficulty whenever metal details don't fit perfectly. A matter of .002" to .005" in fit can mean the difference between a bond with a strength of 2000 psi and a bond of 1500 psi or less at high temperature. The "flow test" used to eliminate unsatisfactory material should be run as close as possible to the production conditions, (pressure, temperature, etc.)

Another problem that plagues the user of supported adhesive(wherein some close-weave fabric such as nylon or glass cloth is the supporting agent)is uneven distribution of adhesive on both sides of the carrier. This cannot be determined readily by inspection techniques during checks for weight or thickness, but can mean the difference between a good panel and a poor one depending on which way the person laying up the panel orients the film.

After sad experience had enlightened us, we devised a "hot patch" test to find this variation and prevent manufacture of poor quality panel. This test is designed to work on adhesives having some volatiles evolved during cure; and so far we haven't found any adhesives that don't fill this requirement. A 2" x 2" square of adhesive is placed on a thin sheet of aluminum, pressed down around the periphery and put in an oven at curing temperature. One sample is made with one side of the adhesive placed against the metal, and the other sample with the opposite side against the metal. If the adhesive distribution is about equal on each side of the carrier, the "hot patch" will show an even raised bubble due to the gas trapped between the carrier and the aluminum. The adhesive surface will be quite even provided the adhesive has good "flow". If on the other hand, one side has a large share of all the adhesive the sample with this side away from the aluminum will show large blisters or craters due to the inability of the volatiles to penetrate without forming these large blisters. Adhesives with poor flow characteristics will show this blistering, no matter what side is toward the metal. With poor flow, the relative amount of adhesive on each side of the carrier has little bearing on"hot patch results".

Admittedly these tests are empirical and do not in any way, shape or manner duplicate the exact production bonding conditions. However, we are able to predict the results of destructive tests on finished panels from the results of these simple control tests.

Detail Part Control: Another aspect of control to obtain good quality bonded panels is the quality of detail metal parts that are to be bonded. There are various factors that effect the measure of control necessary, (1) the closeness of the design allowable and the maximum strength obtainable with the adhesive in question, (2) the flow characteristics of the adhesive used, (3) the pressure applied during bonding, (4) the method of applying this pressure to the parts to be bonded, and (5) whether you are bonding flat or contoured panels.

One thing many people have found out the hard way is that detail part tolerances (especially as to flatness or contour and overall thickness) cannot be underestimated as totheir importance in getting good bonding results. Each type of panel represents a distinct problem; and the various factors mentioned above assume varying degrees of importance. When bonding flat metal-to-metal panels using a high flow adhesive and a fluid pressure from a diaphragm or bag, one only has to worry mainly about burrs, dimples, dings and other imperfections. On the other hand if one is producing double contoured sandwich panels using a low flow adhesive, a semi-fluid pressure device such as a steel air diaphragm with medium to low pressure, the detail parts must be fit as closely as possible. The thought that using high pressure on thin skins (.020"-.030" thick) allows one to bond parts with waves, dimples, dents, etc. can lead to unhappy consequences. To be able to bond high quality panels consistently of any type, one must have the best quality detail parts obtainable within the confines of tools, facilities and over-all economy. Sacrificing quality here can be disasterous.

An important step in the control of quality of detail parts is the pre-fit or trial assembly operation. In general, people bonding precision assemblies will find that pre-fitting of all details prior to even putting the parts in stock is a must. In some cases, drawing tolerances on individual details when additive in assembly result in a part which cannot meet bonded panel requirements.

Tooling aids used in making detail parts may cause repetitive or sporadic bond failures if not controlled. Lubricants in forming operations are definite sources of potential danger. Most lubricants and waxes now on the market contain a certain percentage of silicone resins. Silicones cannot be fully removed by all cleaning methods now used in preparing parts for bonding, and result in adhesive failure at low loads. The big worry is not when a known silicone resin is used, but rather with the proprietary compounds which may or may not contain these resins. It is true that certain adhesives have the ability to assimilate a silicone film on metal and give good bond strengths, but no one in the industry is willing to take this calculated risk.

Handling can be the cause of more "grey hair" among the people responsible for manufacturing bonded panels than any other single thing. The problem rears it's ugly head immediately on receipt of the lug. Thin skins (.010"-.030") must be handled with extreme care to prevent "cans", dings, dimples, etc. This type of discrepancy is far more prevalent as a trouble spot than scratches in Alclad skins. We at Convair have had to reduce handling operations, to adopt special vacuum handling devices, rout or cut multiple sheets at once, and use special boxes to minimize the problem. The use of strippable protective coatings used by every aircraft manufacturer greatly minimized the scratch problem, but has little effect on the problem of dings, dimples and cans which result from handling these thin skins.

In-Process Control and Inspection: After all metal details have been made and prefit is complete, the cleaning, lay-up or assembly, and bonding operations must be controlled. The most important fact concerning these operations is the type of control found most effective.

Unlike most aircraft manufacturing, where the end product inspection and stamp-off is sufficient, we find that in-process inspection and control is vital to quality control of bonding. There are so many variables involved that active on-the-spot inspection results in cost efficiency on an overall basis. Unlike certain routine manufacturing operations where determination of quality is clear-cut, adhesive bonding offers an inspection headache. Many times the basic specification cannot cover the discrepancies that occur. One has to create an atmosphere of maximum watchfulness while operations are being performed in order to insure high quality and low rejection rates.

Control of Equipment, Tools, Etc.: Bonding tools and fixtures must be proofed before they are accepted. This consists of manufacturing a panel and destructively testing the panel to ascertain that the tool resulted in uniform bonds of acceptable quality. Many manufacturers rely on a void check by tapping or other means and a visual inspection after the bonded areas are peeled apart. At Convair we use an ultrasonic testing device to find voids in the glue line. We also cut various test coupons from the critical areas which are tested to determine the actual bond strength. The final check consists of the visual check of glue lines in the remainder of the panel. If discrepancies are found, an immediate check on the tool is made to ascertain whether the tool is at fault, the details are at fault, or whether the cause is unknown. Unfortunately there are cases where bond failure cannot be clearly traced to a definite cause. Additive small discrepancies that individually will not cause failure are usually the cause. Being certain that one can find the production panel that is substandard is the prime concern of the people making bonded panels for use as primary structure. If the exact cause or reason for failure is unknown, it is unfortunate. But failure to find the production panel that is sub-standard is naturally the chief worry. A certain percentage of rejections for "unknown cause" cannot result in loss of an airplane and crew.

Presses, autoclaves and related temperature and pressure recording equipment must be checked periodically to make sure that the required bonding temperatures can be maintained over the whole bonded area. In many cases, the actual heating cycle can also be very critical. Adhesives that evolve considerable volatiles on heat-up as well as cure must be bonded by using a special cycle. This cycle minimizes the volatile problem by allowing volatiles to escape as much as possible.

Control Checks on the Bonding Operation and/or Finished Panels: Even though the process is controlled from the raw material stage through detail part manufacture, cleaning, lay-up and assembly, no one now actively engaged in the manufacture of bonded structures (primary or secondary) would feel safe if they eliminated all tests involving the bonding operation and/or the finished assembly. Even though manufacture of these panels has in all cases received more control and inspection than any other operation in their plant, they do require some physical control tests.

These tests fall into one of the following categories:

(1) Tests on control assemblies.
   (a) Tests on special control assemblies (processed and bonded with the production panel).

(b) Tests on control tabs cut from the production assembly.

(2) Tests on the production panel.
   (a) Destructive tests
   (b) Non-destructive tests

Various combinations of the above tests are used by different manufacturers. In all cases a special control assembly or test tab is bonded with each and every production panel. Everyone has some sort of a non-destructive test on finished panels. The number and type of destructive tests vary greatly throughout the industry.

Most people use special control assemblies processed and bonded simultaneously with the production panel to indicate that all processing operations such as cleaning and bonding were satisfactory, and that the adhesive used was of good quality. If the production assembly involves metal-to-metal bonds only, standard lap shear coupons are used. These coupons are then pulled to see that proper bond strength was obtained. If the production panel is of the honeycomb or sandwich type, a special standard honeycomb assembly is bonded along with it. Shear beams and peel tests are run on honeycomb test assemblies to determine quality. If the production assembly also involves metal-to-metal and honeycomb bonded areas, standard lap shear test panels may be run in addition to the honeycomb test panel.

At Convair, we are adding a test tab area to each production panel which is cut off after bonding and tested. Lap shear specimens are cut from metal-to-metal bonded tabs and tested. In the case of sandwich construction, honeycomb beam specimens as well as lap shear specimens from the metal-to-metal area are cut and tested. Extra work is necessary here in specimen preparation as compared to simple cutting of lap shear specimens from a standard lap shear test panel.

Destructive tests are naturally kept to a minimum in order to get as many panels as possible for installation on the airplane. After initial tool proofing by destructive testing, the percentage of production panels destructively tested may vary from 1% to 20% depending on how critical the nature of the panel. The type of testing varies greatly also. Some manufacturers may require visual check of the disassembled bonded areas, whereas others cut lap shear, peel and shear beam specimens for tests.

Test results from specimens cut from standard test assemblies cannot be directly compared with test results from identical type specimens cut from the production panels themselves. In almost all cases, the results from the panel itself will be slightly lower. This is due to the fact that the standard test assembly represents a relatively ideal condition.

Non-destructive testing is of vital interest to all manufacturers. If a way can be found to test without destroying the panel and be 100% sure that the panel is satisfactory, all the costly destructive tests can be eliminated or greatly reduced.

The Air Force has recognized the importance of non-destructive testing and has awarded several contracts for work on the problem. Methods involving X-ray techniques, radiographic techniques, dielectric measurements, audible sound wave dampening, and ultrasonics have been investigated.

Today however, many people still rely on tapping tests involving special light hammers or serrated wheels (with or without amplifiers) to determine a good bond.

We at Convair are using the "Stub Meter". This ultrasonic testing device was developed by Stanford Research under an Air Force Contract and later modified by Convair. A low frequency ultrasonic wave is coupled to the bonded area by means of a crystal or transducer. The bonded area then becomes part of a resonance circuit or system. The frequency of the wave generator or oscillator is varied over a given band of frequencies. The response is picked up, amplified and shown on an ocilloscope. The wave form is symmetrical and the peak corresponding to the resonance frequency of the bonded joint. The height of this peak is indicative of the nature of the bond. A good bond shows low resonance peak resulting from high attenuation or damping. A poor bond or void results in a high peak due to reduced attenuation or damping. The thickness and type of the adhesive as well as the thickness of the skins, type of core, etc. all effect the basic response. The instrument response is calibrated by measuring the response peak of a known bond or standard. In addition to indicating voids clearly and concisely, the Stub Meter will also show other miscellaneous abnormalities in the bond giving responses in between a clear-cut void and a good bond. Many times a relatively thick glue line or other discontinuity is found in these questionable medium response areas when panels are peeled apart and checked visually.

Although the "Stub Meter" checking technique is slow and time consuming, we feel it is more accurate than conventional tapping. We have been and will continue to correlate destructive test data with "Stub Meter" results. In this way if the correlation is satisfactory, we may be able to eliminate most all destructive testing and the necessity for standard test assemblies and test tabs in the future. The critical nature of these panels to the safety of the airplane however, forces one to be absolutely sure before eliminating any control tests.

Statistical Quality Control: The standard techniques of statistical quality control can be used to advantage in evaluating test data on incoming batches of adhesives and core materials. The standard techniques are also useful in analyzing test data from standard test assembly bonds and test tabs. However, one has to be very careful lest he wind up comparing "apples and oranges" so to speak. There are so many variables involved in bonding operations that one can easily be misled by a quick analysis of the data. In many cases only significant data trends can be established by statistical analysis.

However proper statistical data analysis is the best way to sell management on whether increased or reduced testing is needed. Everyone wants to reduce the amount of control testing, but is beset by fears of okaying a poorly bonded panel.

Summary: The above paragraphs have outlined in general the detailed controls that are now necessary to produce high quality bonded structure. The overall quality control system is much more costly and time consuming than that required for normal riveted structure. When aircraft manufacturers have acquired more statistical data and experience and better non-destructive test methods are developed, the amount of inspection and testing may possibly be reduced.

However, the disadvantage associated with the complex quality control system is trivial when compared to the design advantage of bonded structure in high speed aircraft.

ACCEPTANCE SAMPLING OF A CONTINUOUSLY EXTENDED PRODUCT: STEEL WIRE IN COILS

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American Steel and Wire Division
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Acceptance sampling of steel wire in coils poses many problems not evident to casual observation. Steel wire is imbued with many significant characteristics, some of which are variables and some are attributes. Most existing specifications stipulate acceptance of the product on the basis of either so-called 100% inspection for attributes and one or two tests for variables per coil or on the basis of a percentage inspection and testing of the order of 5, 10 or 20%. These procedures have served both consumers and producers reasonably well for more than 100 years. Why have these procedures, which to the modern statistical quality control engineer seem so unscientific, been so successful? The answer lies in the fact that producers in general possess an inherent integrity and if they don't possess it, they soon acquire it under the compulsive influence of a highly competitive industry. By virtue of this integrity, consumers obtain the quality desired despite, rather than because of, orthodox inspection systems. Note that it was not stated that the old procedures were always the most economical. Sincere efforts by the producer to furnish the quality desired by the consumer can sometimes be very costly to both. Recognition of some of the prescribed and tolerable elements of risk can frequently result in savings to both producer and consumer. It is not within the scope of this paper to elaborate on this aspect of the problem. The objective is to set forth some of the problems involved in acceptance sampling of steel wire on the basis of the principles underlying statistical sampling plans. It is not to be inferred that the observations or statements made represent the procedures or practices of the American Steel and Wire Division.

An understanding of the process of steel wire manufacturing(1) is basic to the recognition of the problems involved in sampling. While some of the quality characteristics of steel wire find their inception as far back in the process as the ore and coal mining operations, this discussion will start with the steelmaking stage. Figure 1(2) is a schematic picture of an open hearth furnace in which a heat of steel is produced. The "heat" is the initial, discrete entity or lot to be considered. Steel manufactured in electric furnaces or in bessemer converters is produced in similar discrete entities. The size of a heat of steel varies with the process of manufacture and also with the size of furnaces in which it is produced.

The initial batch or heat of steel is sub-divided into individual castings, more commonly known as ingots, thus providing sub-lots of the original lot of steel. The next significant step in the sequence of operations occurs after the molten metal has solidified. The product is removed from the mold, re-heated and rolled into a semi-finished product called billets. A multiple number of billets are rolled from each ingot; consequently, each billet is a sub-lot of a sub-lot. This stage is illustrated in Figure 2(2). After another re-heating, the steel in billet form is hot rolled into smaller cross-sections known as rod. Rods generally are still sub-lots of a sub-lot. The oxide scale formed on rods must be removed prior to actual wire drawing. This is done in

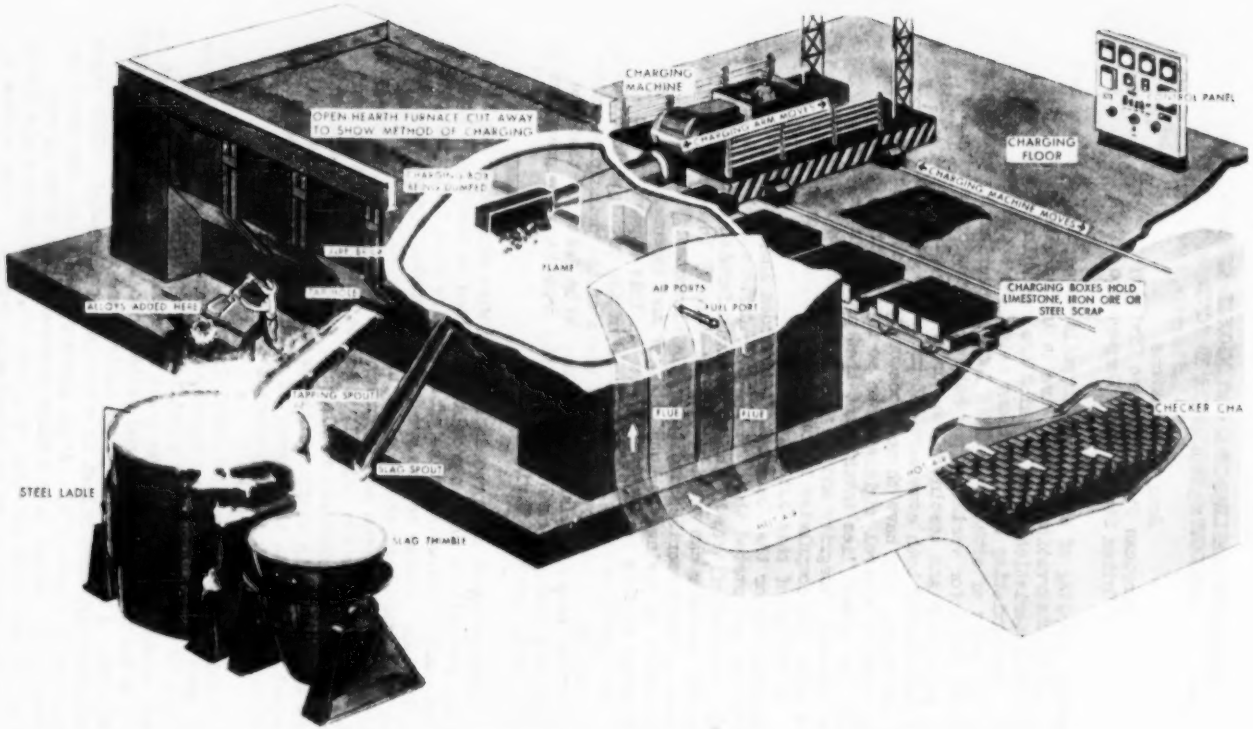

FIGURE 1. SCHEMATIC VIEW OF OPEN HEARTH FURNACE

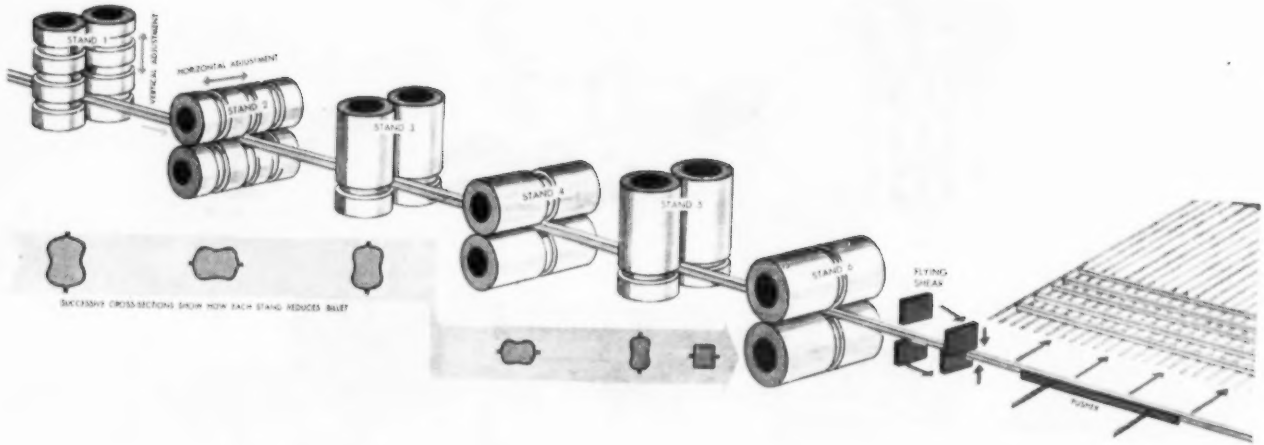

FIGURE 2. SCHEMATIC DIAGRAM OF BILLET ROLLING

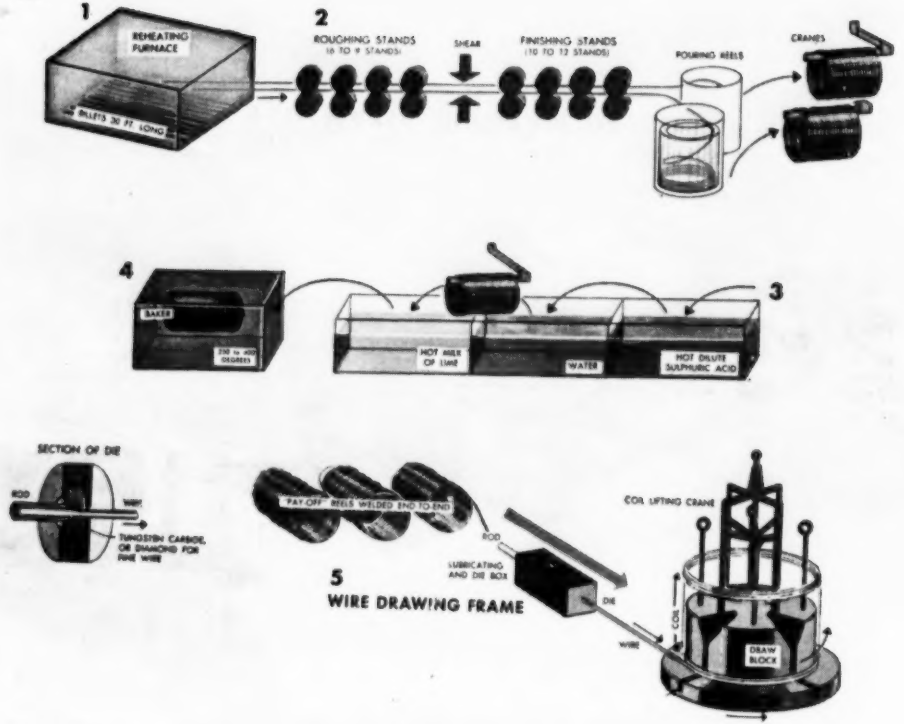

FIGURE 3. SCHEMATIC FLOW DIAGRAM ROD ROLLING & WIRE DRAWING

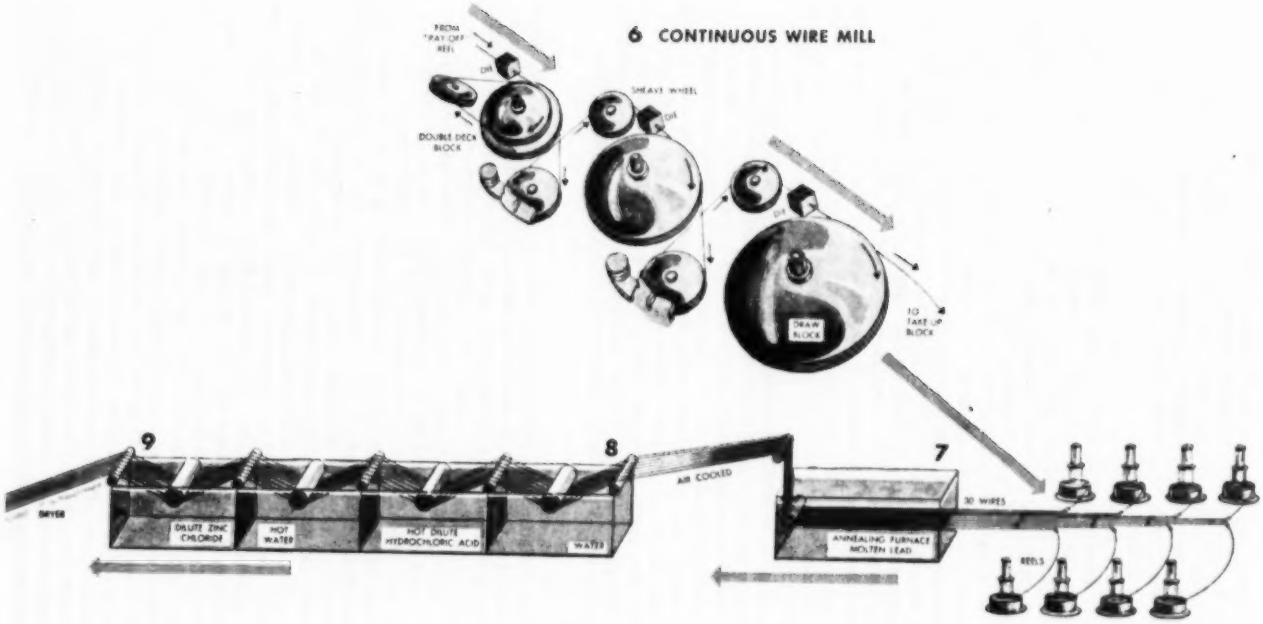

FIGURE 4. SCHEMATIC FLOW DIAGRAM CONTINUOS WIRE DRAWING & HEAT TREATING

the so-called cleaning or pickling operation. The cold reduction in cross-section, that is, the actual wire drawing operation, follows the scale removal as illustrated in Figures 3 and 4(2). This, briefly, is the simplest version of the wire drawing process. Actually a very substantial portion of the rods drawn into wire is given one of several specialized heat treatments prior to the initial drawing. Frequently heat treatment is also required at some intermediate step in the process of reduction in cross-section. Additional, final heat treatments may be involved. Although the individual coils emerging as wire may still be the same entity as the sub-lot of the sub-lot, this is not likely since coils of rods are generally welded together end-for-end prior to drawing and consequently the original rod unit loses its identity as such. If it is necessary to retain this identity, special precautions must be observed. Ordinarily no effort is made to retain the identity of the initial sub-lots, that is the ingots, nor to retain the identity of the sub-lots of the sub-lots, that is the billets. In some instances it may be desirable to segregate the billets rolled from the upper portion of the ingots from those rolled from the lower portion of the ingots. In these cases, identity would be retained to that extent.

The major tonnage of steel wire is furnished in one-piece coils ranging in weight from about 25 lbs. to 1,000 lbs. and over. Some wire is furnished on spools or reels ranging in weight from about 5 lbs. to 600 lbs. and over. Moving this relatively bulky material constitutes a real problem in materials handling. This particular point is stressed because it constitutes an obstacle to the application of the principle of truly random sampling. On completion of the manufacturing operation, the wire coils are stored in nested piles or stacks. The random sampling of coils for inspection and testing purposes would require extra handling and shifting of all the tonnage of wire produced. This operation obviously would not only increase costs, but it would also delay shipments.

The nature and sources of significant characteristics of steel wire are shown in Table I. No attempt has been made to list all the characteristics nor is it intended to imply that those listed are associated with any one given specification for wire. The first two characteristics, the steel grade and the grain size, emanate from the steelmaking operation. They are associated with the heat which, as previously mentioned, is a discrete lot. Determination of the conformance of these characteristics to the specified requirements is made by means of a chemical analysis in the case of the steel grade, and by a specialized testing procedure in the case of grain size. For acceptance purposes, each heat of steel is sampled while the metal is still in the molten stage and while it is being poured into the molds. Samples thus taken are designated as ladle samples. Specimens taken from these samples are subjected to a chemical analysis. The criterion of acceptance is whether the determined percentage of the various elements falls within the prescribed limits for each element. If all elements are within the prescribed limits for the grade of steel being made, the analysis of a specimen from one sample, usually the sample taken during the pouring of the first half the heat, is designated as the representative analysis. Usually this is sufficient evidence of conformance. If, because of specialized application, further evidence of conformance is required, check analyses may be specified. Since steelmaking involves complex, physical-chemical reactions, some heterogeneity of chemical analysis is inherent, therefore, whenever check analysis is required, broader

specification limits are prescribed. The established procedure of sampling for check analysis purposes involves taking a number of specimens, depending upon the size of the lot expressed in tons(3). To date, these procedures have proven adequate primarily because the specification limits and the capability of this closely controlled process are in reasonable balance.

While the austenitic grain size is basically inherent to the heat of steel, it is affected to some extent by the processing variables. Consequently, sampling should be done with care. One sample is generally sufficient to reveal the grain size of a given heat of steel or a particular portion of a given heat of steel subjected to a given set of processing operations.

By virtue of the several handlings entailed in processing steel through the previously described operations, a fair measure of mixing occurs with the result that any sample chosen from the initial lot or heat or from a segment of the heat can be considered to be a random sample representative of the heat or of the segment of the heat, for purposes of determining the chemical analysis and/or the austenitic grain size.

Other characteristics of wire may be functions of one or more of the processing steps. Different definitions of the lot must be set up for such characteristics. The definition of the lot under these circumstances must be rational with respect to the characteristics being examined. For example, with respect to size, that is, diameter, a lot should obviously consist of wire of only one nominal diameter. The diameter of a wire is controlled by the diameter of the die through which the steel is drawn. Tungsten carbide is the most commonly used die material. Although tungsten carbide is a very hard material, it does wear and it is occasionally broken or damaged. Because die wear is not always uniform and because of the rare instances of die breakage, the wire may occasionally be "off-size". Failure of the wire to conform to the size and tolerance specified constitutes a defect. Acceptance sampling for conformance to size is feasible with moderate restrictions. One restriction involves limiting the gauging, that is, the location of the specimen, to readily accessible portions of the unit of wire whether it be a coil or a spool. Measurements of the size of a wire at the ends of a coil generally give reasonable indication of the size throughout the length of the coil. Because of the nature of the process of manufacture, it would be an extremely rare occurrence to find size variations between the ends which vary beyond the limits encompassed by the measurements at the ends. Therefore, gauging the ends of coils of wire for determination of conformance to size requirements is technologically sound and constitutes a reasonable restriction. The second restriction concerns the coil sampling procedure. Insistence upon rigorous criteria of randomness would impose an appreciable cost on the product because of the mechanical problem involved in shifting stored material to obtain the selected units. Some departure from true randomness must be accepted if sampling is to be used economically. Otherwise, it might be cheaper to insist upon gauging every coil for conformance to size tolerance. In view of the fact that for most wire applications off-size does not constitute a critical defect as defined in MIL-STD-105a(4), the added and undetermined risk resulting from nonconformance to the strict interpretation of randomness could very likely be tolerated. In other words, realistic selection of samples in as

unbiased a manner as possible and without regard to their quality normally provides adequate protection.

TABLE I

NATURE AND SOURCES OF SIGNIFICANT CHARACTERISTICS OF STEEL WIRE

Characteristic	Source	Association	Determination of Characteristic
Steel Grade	Steelmaking Operation	Heat	Chemical Analysis (Destructive)
Grain Size	Steelmaking Operation	Heat	Microscopic Examination (Destructive)
Size	Drawing Operation	Individual Coils	Micrometer (Non-destructive)
Mechanical Properties	Steel Grade Heat Treatment Cold Reduction	"	Testing Machine (Destructive)
Weight of Metallic Coating	Coating Operation	"	Chemical (Destructive)
Surface Seams	Rolling and Steelmaking Operations	"	Etching or Mechanical (Destructive)
Cracks	Various	"	"
Scratches	"	"	Visual
Rough	"	"	"
Dirty	"	"	"

As indicated in Table I, the mechanical properties induced into steel wire are functions of the chemical analysis of the steel, the type of heat treatment employed, if any, and of the amount of cold reduction by drawing. Since these three variables can be manipulated, within certain limitations, to produce essentially the same end results, it is desirable that the lot be confined to material produced by one manufacturing sequence. Defective mechanical properties traceable to the chemical analysis will generally be characteristic of an entire coil and when they do occur, such coils are most likely to be randomly distributed throughout the lot. With respect to the influence of heat treatment on the production of defective material, the particular type of heat treatment employed will have a bearing on the nature of occurrence of defective material. In the batch type operation when failures do occur they are most likely to be in strata — either at the top or at the bottom of the charge — and the entire coil may or may not be affected. In the continuous type of heat treatment where the rod or

wire is passed through the heat treating media as individual strands, when failures occur they are also most likely to appear in strata. But in this case the strata are within coils -- from front to back end. Thus, the occurrence is not random. Failures in mechanical properties traceable to the cold reduction in drawing to size are most likely to be characteristic of the entire lot. However, there may also be instances associated with variations in the speed of drawing in which case only portions of coils are affected. Here again the occurrence would be stratified or non-random. Table II presents a summary of the nature of the occurrence of defective material. From this it will be seen that the technology involved in imparting mechanical properties to steel wire is such that in most instances the occurrence of non-conforming material is non-random.

TABLE II

OCCURRENCE OF FAILURES IN MECHANICAL PROPERTIES BY POTENTIAL SOURCE

Potential Source	Occurrence	
	Within Lot or Between Coils	Within Coils
Chemical Analysis	Random or Non-random	Non-random
Heat Treatment		
Batch Type	Non-random	Non-random
Continuous Type	Random or Non-random	Non-random
Cold Reduction	Non-random	Non-random

The same observations apply with respect to the weight of metallic coating. Since the application of metallic coatings is performed as a continuous operation similar to the continuous type of heat treatment, the occurrence of defective material follows the same general pattern.

The characteristics listed in Table I under the general heading of Surface are also associated with individual coils. The occurrence of coils with such defects may usually be considered as being random and the occurrence of these defects within coils is also usually random. In some instances, due to a faulty setup, a number of coils with the defect throughout their entire length may be processed in succession, thus making the occurrence non-random.

Random selection of sample units (coils) could be accomplished under the same penalizing conditions mentioned in connection with sampling for size. The limitation concerning the location of the specimens taken from the sample, that is, that specimens be taken from the ends of the coils, is more significant in view of the fact that the specimens must be subjected to destructive testing. Therefore, if the continuity of the coils is to be preserved, the specimens must be taken

from the ends of the coils. The technological assurance of uniformity from end to end of the coil must be tempered when considering mechanical properties and weight of coating. The variability of the characteristics which exist within coils is not necessarily bounded by the results obtained on the specimens taken at the ends as in the case of size determinations. Since the specimens must be taken from the ends of the coil, each possible specimen does not have an equal opportunity for selection. This condition is at odds with the requirement set forth in the "Supply and Logistics Handbook H-105"(5) which states that, "Basic in the drawing of any sample is the requirement that the procedure used to select items from the inspection lot should be such that each item in the lot has an equal chance of being included in the lot." For this reason, specifications stipulating sampling in accordance with Mil-S-105a are not generally accepted by wire manufacturers without a waiver or a clarification of the location of specimens with respect to their position in the coils of wire.

It might be argued that each unit of length which could have been produced from the original lot (or segment of segregated lots) has an equal chance of occurring at the ends of coils. However, for any fixed operating setup this is not so since the divisions which are made between ingots and between billets and between rod coils preclude that units in between these divisions can occur at the ends. Some minor variation in location naturally exists, but certainly not to the extent that it can be said that selection of specimens from the ends of coils constitutes a procedure which is in full compliance with the requirement of objective randomness. Hence, with respect to those characteristics associated with individual coils, truly random selection of specimens is impractical. To what extent non-random selection of specimens for the determination of non-randomly distributed characteristics nullifies the effectiveness of statistically designed acceptance sampling plans constitutes one of the major problems with respect to the application of such sampling plans to steel wire. Naval Ordnance Standard OSTD 80(6) modifies the requirement of random selection of samples stipulated in MIL-STD-105a by requiring that the units of the sample be selected merely without regard to their quality. This is a heartening development and if substantiated by further promulgation of this concept, the problem of acceptance sampling of steel wire will be considerably simplified.

Obviously, insofar as a continuous product such as wire is concerned, there is no alternative to sampling. To quote Mr. Harold F. Dodge, "Thus, if there is no alternative to sampling, a specified limit for an individual piece is unenforcible. When sampling is employed, there can be no absolute assurance that the limits have been met; instead it is possible to have only a degree of assurance as measured in terms of probability."(7) Despite the fact that this observation was made as long ago as 1932, failure to take cognizance of this limitation still constitutes one of the problems in the application of acceptance sampling to steel wire. The "degree of assurance" when the basic requirement of random sampling is violated has not yet been evaluated. Establishment of specification limits on the basis of data obtained from processes which are operating in a state of statistical control will provide a realistic approach towards the solution of the problem of determining the degree of assurance provided by a process. This phase is clearly a responsibility of the producers. The evaluation of the degree of assurance provided by any given sampling plan involving the

limitations with regard to non-random selection of specimens is a problem for persons highly skilled in statistical mathematics.

Despite the various limitations discussed above, there are, currently, numerous government and private consumer specifications invoking acceptance sampling procedures for steel wire. With very few exceptions, these can still be considered to be interim specifications because of the fact that in most cases neither producers nor consumers are being held to the producer-consumer risk features of such sampling plans. In other words, regardless of the fact that material has been accepted on the basis of a sampling plan, the producer is still held responsible for any non-conforming material and on the other hand, when material is rejected by acceptance sampling plan, the producer seeks reconsideration of the lot on the basis of additional sampling or sorting. If the full benefits of statistical acceptance sampling procedures are to be realized in this area, a solution of the problem and definition of the risks involved in selection of non-random specimens must be developed. The basic problem appears to hinge upon the statistical significance of non-random selection of coils which may be either randomly or non-randomly defective, and on non-random selection of specimens which are non-randomly defective. Progress towards the greater utilization of statistical acceptance sampling plans will hinge on the solution of the problems mentioned and upon the economic feasibility of the sampling plan specified.

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QUALITY CONTROL IN AUTOMOBILE FRAME PRODUCTION

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Quality Control Staff
A.O. Smith Corporation

Fig. 1 is a typical automobile frame. It consists of some 70 parts (not all shown) put together with 33 rivets and 283 welds. It is the foundation upon which an automobile is built. It is only one of many component parts and sub-assemblies that go into the finished product. It must be made so that components, which come to the assembly line from many manufacturers in many parts of the country, will readily assemble and be properly positioned. It consists almost entirely of steel stampings and steel stampings are subject to considerable variation due to chemistry and metallurgy of the steel itself as well as to the many variables in the fabrication of the parts.

There are approximately 400 operations required for the assembly of a frame any of which can be defective at any given time. The possibility for the occurrence of errors is tremendous and that they do not occur any oftener than they do is because we have tooled up to "foolproof" as many operations as we can and also because our operating personnel are constantly made aware of the need for doing a quality job. We couldn't possibly hire enough inspectors to check every frame for all defects that might occur. The process and the operating personnel must make it right in the first place and check it as they make it. This is not just a philosophy, it is a cold, hard economic necessity.

The inspection of dimensions on an automobile frame is not easy. It cannot be done on the line as the frame is being assembled. In the first place it is physically impossible to do so and secondly no dimension so measured is valid until the frame is completed. Subsequent operations alter the intermediate dimensions. The only kind of inspection which can give accurate results is the conventional layout inspection which is a laborious and time consuming operation. Only two frames a day per layout table can be handled in this manner as compared to a production rate of 150 to 400 frames an hour. For years this was the only way we knew how to measure the many dimensions on a frame. It was obviously inadequate as a quality control device and we knew it but nevertheless we kept average and range charts on the layout inspection results and we learned many things of an informatory nature. In many cases by the time we had enough data for an analysis the problem was long gone but perseverance is a remarkable virture, especially when there is no other way to approach a job, and we were able to make some real progress as time went on.

The introduction of the $\bar{x}$ and R chart helped immeasurably in interpreting the data obtained from our layout inspection. Bear in mind that these charts were kept at what amounted to the final inspection station which admittedly is not the place to keep them. Any quality control man will tell you that an $\bar{x}$ and R chart does the most effective job when it is kept right at the operation so the operator can see it and adjust his operation accordingly. To this we agree, but we also maintain that $\bar{x}$ and R charts at the end of the line are better than none at all. But, difficulties notwithstanding, it is still imperative that knowledge be imparted to the man doing the work if quality is to be truly controlled.

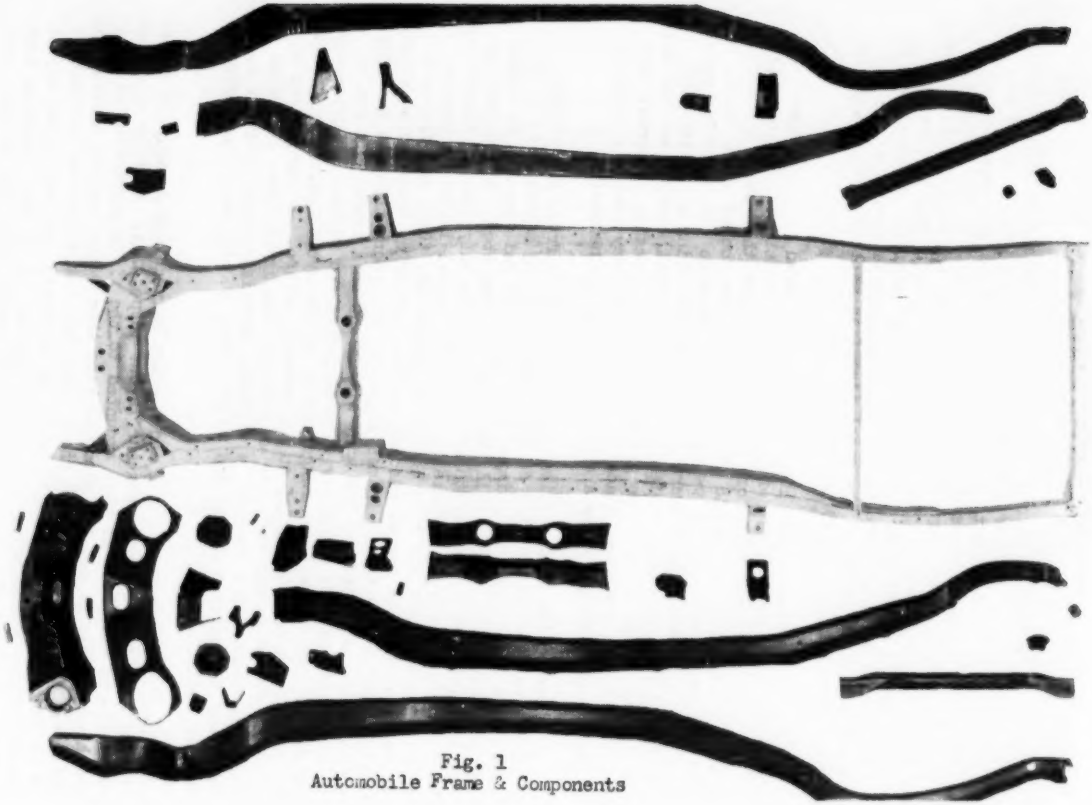

Fig. 1
Automobile Frame & Components

To do this we hit upon a device called a dot chart. This chart is located at come point along the assembly line convenient to the line supervision.

The dot chart lists all dimensions that are to be measured on the frame. For each of these dimensions there exists an individual average and range chart. For a given frame model this can mean as many as 90 charts. They are kept by the layout inspector in a loose leaf binder. When five frames have been checked and 90 averages and ranges calculated this information is transferred to the dot chart by means of a colored dot. Originally a green dot meant that the dimension was in control and also within specifications. In other words it was not a problem. A black dot meant that a dimension was in control but not within specifications. This chart gave the foreman a quick and easy summary of the results found by the layout inspector. A preponderance of red dots meant trouble. As they decreased in number and the chart became mostly black and green he knew that his corrective action measures were truly corrective. When he wanted detailed information in connection with red dimensions he could always get it from the $\bar{x}$ and R chart at the layout table. As it turned out this became the first stop he made when he saw "red". There was never any question about these quality control charts being looked at by the right people. They were and are scrutinized.

Before long it became evident that the notion of "in control" as used in the case of the original black dots served more to confuse than to help. Also in time the operating people when they examined the $\bar{x}$ and R charts soon learned to differentiate between trouble that showed up on the average chart and trouble that showed up on the range chart. So the colored dots were given new meanings. The green dot kept its original meaning of "no problem". The black dot now means out of control in the range, and the red dot means out of tolerances as shown by the average, or by both the average and range. This simplification has been much more helpful.

Fig. 2 is the dot chart today. The green dot has given way to a simple horizontal dash. This not only is much easier to apply but it also serves to emphasize the red and black dots. Note that 54 dimensions are listed. This becomes 108 because an automobile frame has right and left hand symmetry for the most part. The long horizontal lines indicate those dimensions where the symmetry does not exist. This chart covers more than one Pontiac frame model and the slated lines indicate that certain dimensions were not a part of the frames being produced during the time periods as shown. The figures in the tolerance column express drawing tolerances in sixty-fourths of an inch.

The dot chart has turned out to be as simple and as effective a method of communicating control chart data to the assembly line as we could devise. The floor inspector or, as we call him, the line inspector has the responsibility of keeping the dot chart current. This makes it mandatory that the line inspector look at the control charts and by so doing keep himself abreast of the line performance. These $\bar{x}$ and R charts, kept in a loose leaf binder at a layout inspection table get more attention than many such charts in plain view.

One reason for this is that the dot charts which derive from them are the bases for reporting an index of dimensional quality to management. An index of 90 or above is currently considered as satisfactory.

QUALITY CONTROL

FRAME DIMENSION "DOT" CHART

DEPARTMENT 1144

MODEL PONTIAC

PROCESS IN TOLERANCE –

PROCESS OUT OF TOLERANCE •

RANGE OUT OF CONTROL •

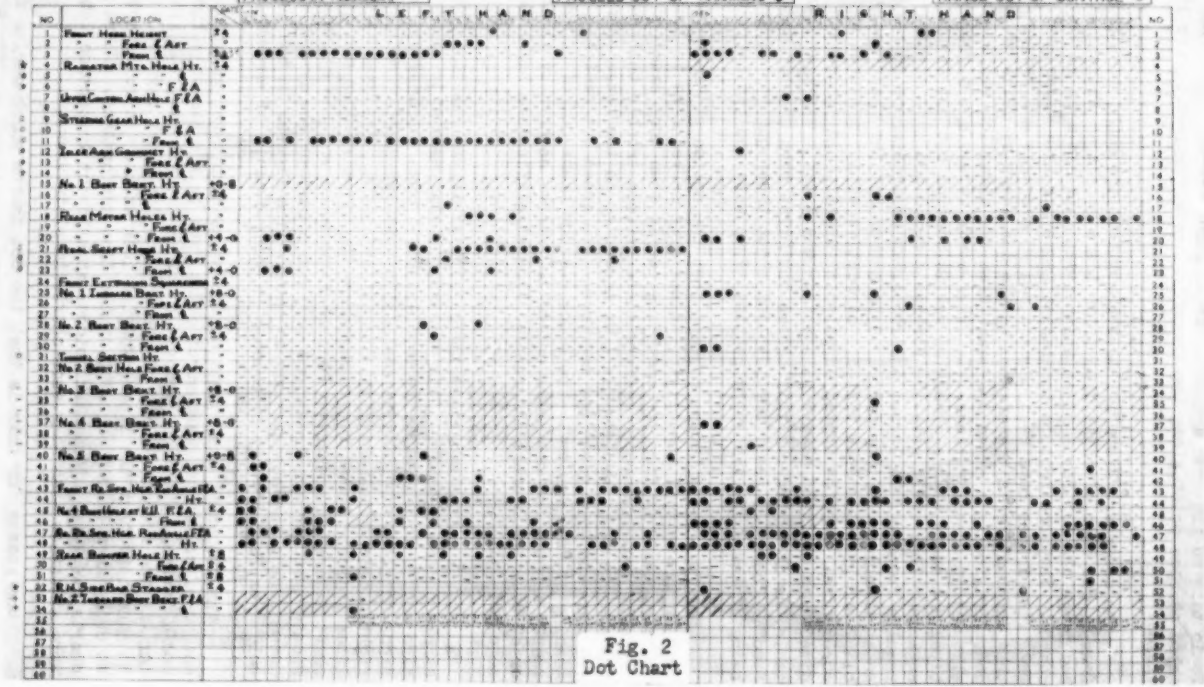

Fig. 2
Dot Chart

When it drops into the eightys or below, as it might do on occasion, questions are asked and answers demanded and there is no relaxation until the index again becomes satisfactory. Calculation of the index is extremely simple. Quality control practioners will recognize it immediately as the percent effective:

$$100 \times \left(100 - \frac{\text{No. of black and red dots}}{\text{Total no. of dimensions checked}}\right) = \text{index.}$$

It is not reported as a percentage but simply as a number. Not many profoundly calculated indexes get more managerial attention and, what is much more vital to product quality, result in more effective corrective action.

Any frame at any given time will have some dimensions in control but not within specifications. If this seems paradoxical, let me point out here that to a quality control engineer the term "in control" takes a somewhat different definition than the common one. Commonly the term "control" implies that things are running smoothly with everything according to specifications and consequently no one has a problem. To a quality control engineer the term means that an operation is functioning uniformly and that every piece coming from it is as nearly like every other piece as the process can make it. That this area of stability might be at an unsatisfactory level of quality does not contradict the definition.

We are and have been producing some dimensions as uniformly as we can but unfortunately they do not meet the drawing in all respects. It would be asinine on our part, in the enlightened quality control atmosphere which prevails today to deny such a situation. Our competitors as well as our customers are faced with the same problem. We not only know that such conditions sometimes exist, but we also know to what degree they exist, dimension by dimension and we know when corrective action is truly corrective. These dimensions do not alarm us unduly. This is not to say that we ignore them. We are constantly striving to make these and all other dimensions agree with the customers specifications. There is nothing in our experience to lead us to believe that these conditions have not prevailed for a long time. Moreover, many automobiles have been built without difficulty on such dimensions and they have lived to a ripe old serviceable age. Once upon a time we operated on the assumption that if a customer did not complain about a dimension it must therefore have been made to drawing specifications. Today we know better. There are many problems in a frame. We give our first and immediate attention to those which give the customer trouble. Those which give no trouble will be corrected as we get to them.

The $\bar{x}$ and R charts led us directly into process capability studies and early in our experience when the time was ripe we confronted our engineers with the results of these studies. The ripeness of time is strictly an intuitive problem and what seems ripe to a quality control man may be rotten to an engineer. We got the usual polite but passive interest which to the novice can be so thoroughly chilling and completely incomprehensible. But like everyone else engineers must overcome a certain amount of inertia to new ideas and the quality control devotee who really knows the power of the statistical technique soon learns the virtue of perseverance. We kept pressing the point until now our engineers refuse to enter into a discussion of dimensions and tolerances unless they have a capability study before them.

Once upon a time one lonely liaison engineer had the responsibility of discussing tolerances with the customer on new frame models and he had to do it with almost no knowledge of the natural tolerances of our shop processes. From this vantage point in time we wonder how he ever made any progress, just as we wonder how our forebears could get anything done without telephones, for example. But they did and so did he. Now he has the help of a committee, or team, or task force or whatever you want to call it because the holding of a dimension and tolerance is a cooperative venture. The day when a man can put a tolerance on a drawing and expect it to be held by edict is on its way out. So now a tolerance is discussed in committee by the liaison engineer, the product engineer, a manufacturer, and a quality control man armed with his process capability data.

And what form does this process capability data take? It is nothing more than a normal frequency distribution curve constructed from an average and a standard deviation as revealed by the control charts. The curve is based on a suitable scale and it is shown in relationship to the specified tolerances with the estimated percentages out of tolerance indicated thereon. It is an extremely simple line drawing that in time has come to have real meaning to our engineering group. So much meaning that early in 1956 they requested the quality control group to conduct a short course in statistical quality control at which the automotive engineers were required to be present.

Dimensions and tolerances of a frame are fixed by the customer. We cannot make any changes to any drawings without authority from the customer. When we find ourselves faced with an unrealistic drawing requirement it is necessary to go back to the customer for relief. Such a practice in the past got us nowhere. From experience we learned that the customers' drawings were exactly what he wanted and that we were expected to make the frame just that way. The fact that we could not meet some of the requirements, coupled with the fact that frames had been made that way by the thousands and used with no apparent ill effects made little difference. This led to a "let sleeping dogs lie" attitude on our part. It has been only comparatively recently that our engineers, armed with the facts as described by our quality control people, have tried again to get some relief from some of the more unrealistic requirements of the drawing. Reflecting the general progress of Statistical Quality Control throughout the country, they have been very successful thus far.

To the Quality Control group it has long been obvious that the layout method of analysis was totally inadequate from a speed standpoint. Two frames a day per table simply were too few for the right kind of quality control. The $\bar{x}$ and R data made it very plain that a more rapid means of checking frames had to be found. In all fields whenever a critical need for a better method is an obstacle to progress, sooner or later a better way is found. We found one. Our automotive people came up with what might be called a mechanized checking table which uses a system of scribed flush pins. (Fig. 3). Management needed some convincing that the cost was worth it, but from what had been done in the area of quality cost reduction from the meager data we had been getting, and because of the ever increasing demands for more precision in the frame, the necessary appropriations were granted and the tables were made. Where we once could check only two frames a day we can now check two to four an hour. This increase in our sample size enabled us to get better control over our assembly lines and to get better process capabilities faster.

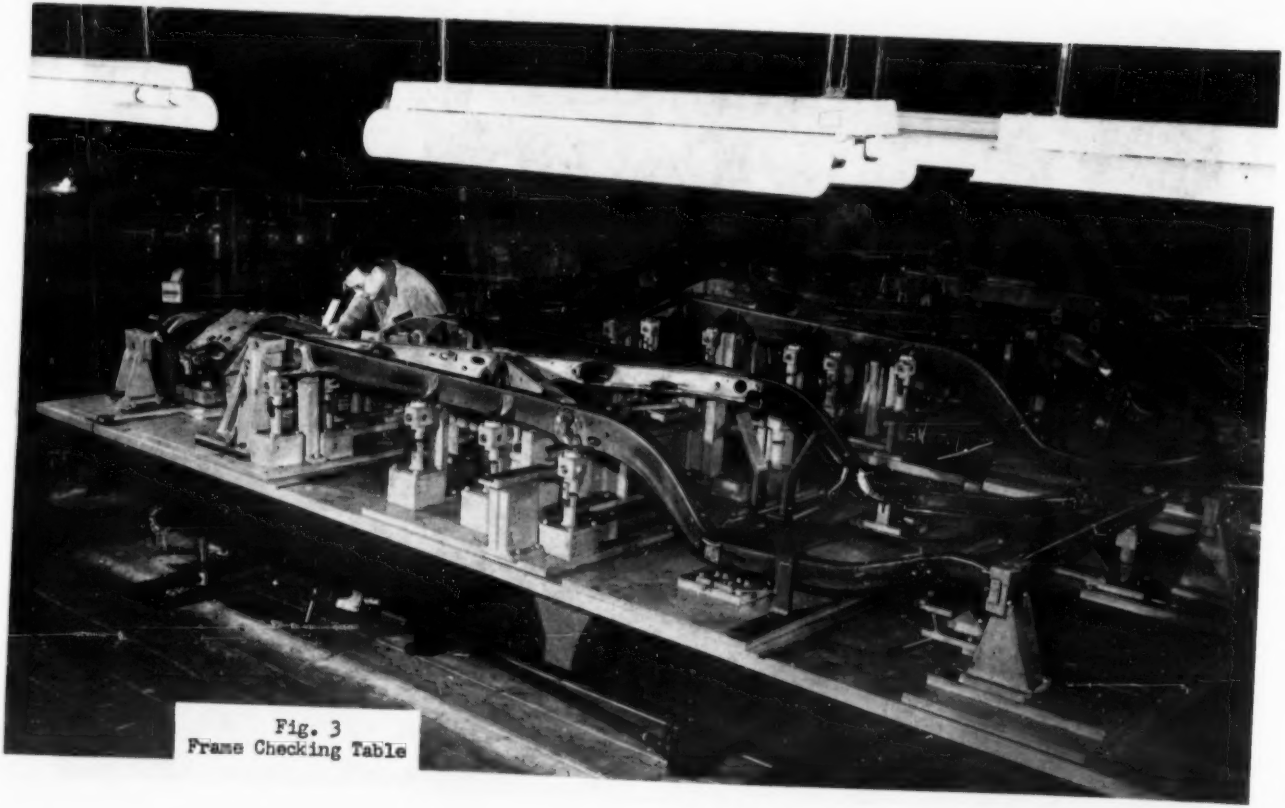

Fig. 3
Frame Checking Table

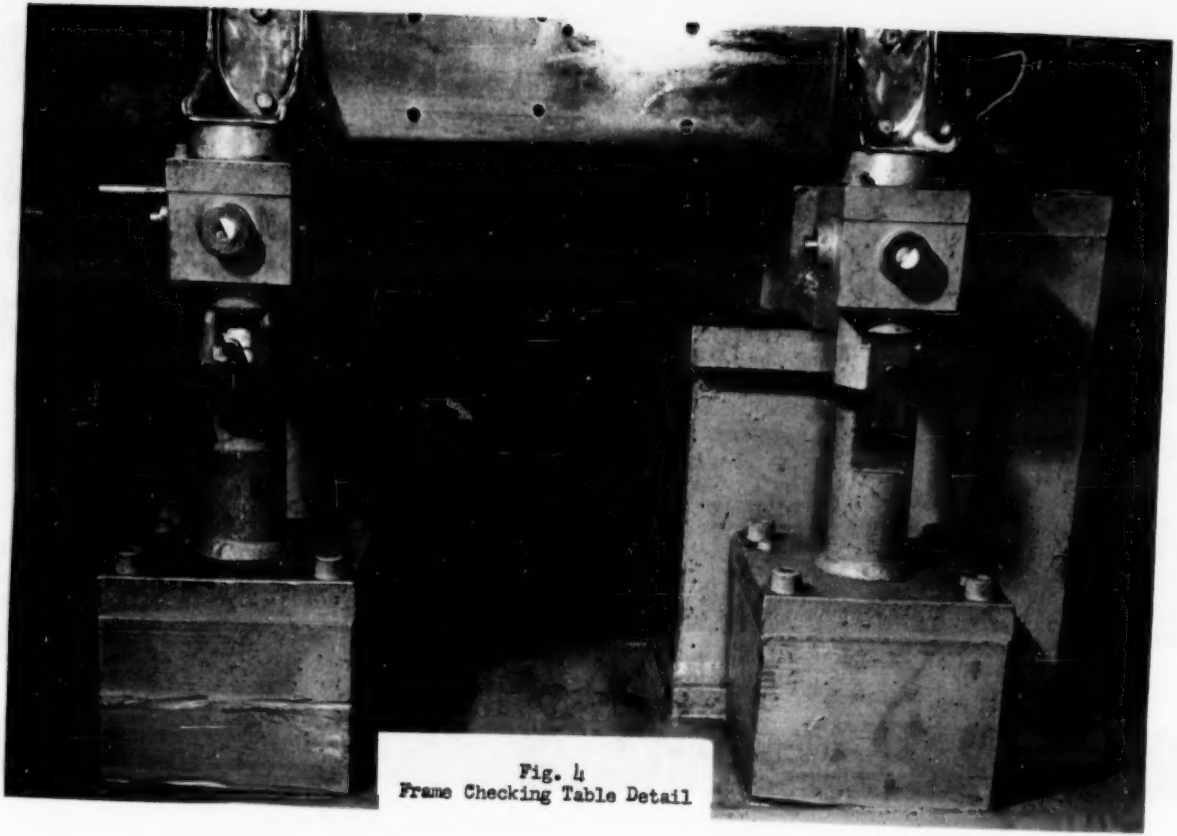

Fig. 4
Frame Checking Table Detail

Fig. 4 is a detail of the table which is of interest in that the fixtures shown are not attached by the usual bolts but by a plastic cement developed in our laboratories. This eliminates the bolt holes and gives us greater flexibility.

A frame is put together with about 250 to 300 separate welds. Many of them are not more than tack welds made on straight horizontal sections that carry no excessive stresses and strains. Others are in difficult places to get and are in highly critical areas such that a weld failure might be the cause of a wreck on the highway. Between these two extremes are all the rest of the welds. The only practical way to inspect frame welds in the shop is by looking at them as the frames come off the assembly line. Cracks, porosity, holes, undercuts, etc. are visible and can be marked out for repair. But visual inspection does not really evaluate a weld from a functioning standpoint. We have from time to time cut up frames and tested welds destructively for fatigue and tensile strength among other characteristics, and we find that some of the most unlikely appearing welds passed these physical tests with flying colors while some beautiful looking welds have failed. Also, looking at all the welds is a 100% visual inspection job and it has all the shortcomings of any other kind of 100% inspection. Anyone whose job it is to visually evaluate welds will recognize this problem. Meaningful physical testing is slow and it is destructive so it cannot be done in quantities large enough for control purposes to compensate for the time and money spent on them. The only other approach to the problem is the control of the welding process itself.

The search for the better way to assurance of weld quality has gone on continuously at A.O. Smith from the time a frame was first welded. Since about 1948 when we first became seriously interested in statistical quality control we have used all of the usual statistical techniques and some of the unusual ones, and we have had to put together some home-made techniques to meet specific problems or what we at the time thought were special cases. The dot chart described above was one that hit pay dirt. Many others lie buried in the files. But the point here is that each approach to the weld problem got us just a little bit farther along. Our latest effort was a combination of statistics, and that most valuable attribute of the statistical method, straight forward thinking. The most significant lesson taught by statistical quality control is the necessity for straight thinking before and during the collection of data such that the analysis of that data and its presentation to management will result in a decision.

Numerous steps had been taken in the past that made it possible to launch our latest weld improvement program in December, 1954. It started out rather unimpressively with one more meeting "to improve frame weld quality and reduce repair costs". Present were representatives from Engineering, Manufacturing, Quality Control, Weld Laboratory, Management, Time Study and others. Assignments were passed around freely.

1. ENGINEERING. Classify weld quality according to strength and rigidity requirements.

The notion of classification of defects was not a new one. This had been done before from a visual standpoint but the engineers were now going to review the past work and improve on it. They came up with three classes which were to be symbolized and shown on the drawings.

Class A. Welds designated as Class A are highly stressed and must be first class commercial welds. No class A weld must be less than a specified length.

Class B. These are stressed welds important from both strength and rigidity considerations. They are not as critical as Class A welds. Their fused length may be shorter than class A welds.

Class C. These welds are of lesser structural importance than class B welds. Their length specifications are the same as for class B but they need not be of the same visual quality.

2. WELDING RESEARCH LAB. Establish amperage ranges to be used on the assembly lines.

By the insistance of the manufacturing group, Time Study cooperated in this assignment. Ours is a piece work shop and manufacturing was keenly interested in what the "best" amperage, as recommended by the laboratory, might do to line speeds and pay rates. The problem was clear. High amperages meant faster welding, but they also meant poor weld quality. The two viewpoints must find a common ground.

3. WELDING RESEARCH LAB. Specify the best welding electrode.

One of the many products of the A.O. Smith Corporation is welding electrodes and the Laboratory is continually developing new, different, and better electrodes to meet the many demands of industry. Now was the time to "make some shoes for the shoemaker's child". The electrode used most in frame welding was found to be not as good as another weldrod.

4. ALL. Establish visual weld standards.

An earlier step had been the establishment of visual standards. They were to be reviewed and brought up to date.

5. WELDING RESEARCH LAB. Develop a weld quality evaluation session for quality control and manufacturing inspectors in order to arrive at a consistent inspection criteria to be included in the regular two week welding course presented by the Welding Institute.

All too often weld quality depends upon who looks at it. When we first set up visual standards we had some sample welds evaluated by all those around A.O. Smith who thought they knew a goold weld from a poor one. There were scores of such persons. We knew that opinions of visual weld quality were a "dime a dozen" but we were not prepared for the widely scattered range of opinion our evaluation experiment revealed at that time. However, out of this welter of opinion a visual standard was set up. Now to support the new standard mentioned above the laboratory was to outline a course of welding instruction which eventually was expanded to include persons from groups other than quality control inspection.

6. ENGINEERING AND WELD. LAB. Establish fit-up requirements for future tooling.

Perfect fit-up in stampings is impractical just as perfect quality,

(zero percent defective) is impractical. Out of this assignment was to come some realistic fit-up recommendations.

The quality control group was the catalyst in this program. They designed experiments, analyzed data, interpreted statistics and made recommendations to the manufacturing group. Analysis of Variance was used in its simplest forms but yet more extensively than we had ever used it in the frame shop up to this time. It is one of the more powerful statistical tools even in its simple form and it enabled us to reach some definite conclusions regarding the best weldrod to use, the best amperages, and the best fit-ups to achieve the desired weld quality. Some of the variables subjected to the analysis were:

a. Type of weldrod (3 levels)
b. Diameter of weldrod (2 levels)
c. Fit up of parts (4 levels)
d. Amperage (6 levels)
e. Stock thickness (3 levels)
f. Welding speed

Welding speed did not enter into the analysis of variance but was used in a linear correlation analysis with types of weldrod (a) and amperage (d). All of the foregoing variables were not put into one large analysis of variance but they were put together in many smaller combinations for the sake of simplicity. Also we felt that we could do more with the interpretation with smaller analyses than with the larger ones all complicated with interactions. If this makes the statistician shudder let me state that from this approach we learned all that we could assimilate at one time. At some time in the future we may find it necessary to design more elaborate analyses but right now enough is enough. Some results we obtained may be of interest.

A. Fit up accounted for 60% of weld quality
Amperage " " 14% " " "
Human element " " 26% " " "

B. With good fit up conditions (flush to 1/16" gap), higher amperages result in a definite deterioration of weld quality.

At poor fit up conditions (3/32" to 1/8" gap) weld quality is poor at all amperage levels. In general bad fit up results in inferior weld quality regardless of amperage, and high amperages results in inferior weld quality regardless of fit up.

C. Complete elimination of one weldrod diameter with one thickness of stock.

There were other results of considerable interest to us but of little or no general interest. The important point here is that our results were in quantitative terms that enabled us to convince operating personnel that some welding procedures and practices needed revising and more careful supervision. We produce a much better frame today because of this work.

DEVELOPING A QUALITY CONTROL PROGRAM FOR AUTOMATION

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In considering the variety of problems that are encountered in developing a quality control program specifically for automation operations, it is of primary importance that serious consideration be given to the basic differences between non-automated and automated systems of manufacturing. During the past four years, many companies have discovered that most of the quality control and statistical techniques which were employed previously on non-automated programs become inadequate when applied to an automatically controlled process.

The first step in developing a quality control program for automation is to develop an automation program that will facilitate the control of quality. Entirely too many companies have made the unfortunate mistake of expending tremendous portions of their capital investments on an automated process only to discover that the process could not be controlled effectively quality-wise or cost-wise. This is indeed a misfortune, since the two primary selling features of an automated process are Reduced Cost and Improved Quality. If these two goals are not attained, the investment is worthless.

During the past twenty years, statisticians have developed such a variety of quality control techniques and statistical applications that practically no production operation today is free from the scrutinizing eyes of a quality control engineer. Unfortunately however, many of the quality control engineers do not realize themselves the basic differences which exist in an automated process as opposed to the manufacturing methods that have been used over the years. For this reason, many of the statistical applications which have proved successful on a particular operation fail miserably when this same operation becomes automated. This lack of understanding is not confined to quality control engineers. Many of the quality control managers, as well as other members of top management are also gifted with this lack of mental progress.

Automation in itself does not represent a new science. As far back as 1928, automation equipment was used in certain machining and assembly operations in various industries. (1) At that time however, these systems were not referred to as automation operations. During recent years, the word "automation" has developed a variety of definitions. In most present-day applications however, these "automation programs" represent nothing more than a highly mechanized system of material handling, along with a few new twists on machine loading and unloading. This does not mean that the experts have misled us in their definitions of automation, but rather that the many degrees and applications of automation are misinterpreted, not only by those who utilize this type of equipment but also by those who design it. Basically, there are two degrees of automation....static and dynamic. In the static degree of automation, a machine, or group of machines, performs a series of related actions at the touch of a button. In the dynamic stage, these same machines not only operate automatically, but continually compare their performance with a desired standard and make corrections as they are required.

Before the actual quality control program can be developed, it is essential that an understanding be attained as to the complete order of automaticity, above and beyond the simple definition of static and dynamic automation, as given above. In Figure A, the nine basic steps, or degrees, of automaticity are expressed (2), indicating not only a definition of each phase, but also a typical example within each step.

ORDERS OF AUTOMATICITY

	CLASS	EXAMPLE
0.	Non-Powered	Hammer
1.	Power Division	Drill Press
2.	Powered Feed	Lathe with Power Feed
3.	Programmed	Automatic Screw Machine
4.	Closed Loop	Automatically-gauged Grinding Machine
5.	Equation-Solving	Radar Gun Director
6.	Decision-Making	Automatic Elevator Control
7.	Machine that Learns	Automatic Punch Press
8.	High-Grade Judgement	Remington Rand's Univac

Figure A

Steps one through eight represent, in one form or another, a degree of automation. Steps three through eight represent a cybernetically-controlled process, in the sense that the operation is "programmed". Steps four through eight constitute those degrees of automation that are computer-controlled. In this latter type, the operations are not only "programmed" but are also capable of making "decisions", on the basis of information which is fed to them through the means of electronically-processed tape or audio frequencies. Upon consideration of this one attribute, it is obvious that the use of this latter type of equipment connects the gap that has existed for many years in quality control programs, which is commonly referred to as "the human element". Machines that can reproduce production quality and are capable of correcting their own mistakes, on the basis of an established standard, can easily nullify the value of a quality control statistician. This does not mean however, that a quality control representative is not needed, but rather that a <u>different type</u> of quality control technician is required, in addition to a complete revision of the applications of statistics and control which were previously used.

To develop a complete quality control program that will effectively measure, analyze and control the capabilities and efficiencies of an automated process, three basic factors are required:

1. Quality control technicians must be utilized, who are trained specifically in the fundamentals of automation, in addition to their complete understanding of the fundamentals and applications of statistical and inspection techniques. In the present day inventory of quality control personnel, there is an abundant supply of half-trained technicians. Through specialization, these men have become so thoroughly familiar with a particular type of manufacturing process that many of the present day quality control programs become ineffective as soon as the manufacturing process is converted to automatic programming. To accomplish any job, we must first have personnel who are capable of doing the job.

2. Once the organization has been staffed with an adequate amount of qualified personnel, we must provide these men with the proper tools. As in the case of the automated process itself, whereby a different type of tool is required, so too with the quality control program. The quality control technicians must be equipped with the statistical weapons of charting and analysis, as well as a revised set of mathematical formulae, in order to accomplish the program requirements. Many of the older types of $\bar{X}$ & R charts will have to be revised to incorporate the changes in inspection frequency that are effected by automated processes, as well as to allow for "process qualification". On operations which formerly required a statistical sample of 5 pieces per hour, an inspection frequency of one sample per one hundred pieces produced will usually provide as accurate an analysis of quality. The effect, however, will provide a reduced inspection cost to the operations. On other types of automated operations, 100% inspection will be utilized in preference to statistical sampling, because of its increased accuracy. When performed on a completely automated operation, 100% inspection will always prove more accurate than the best of statistical sampling plans. In addition, it is wise to note that the various levels of inspection plans, such as reduced, tightened and normal inspection, will be used very rarely on an in-process operation. Instead, the frequency of inspection will be changed, depending on the product quality. In all cases however, the standard of inspection will remain the same.

3. The third and most important step in our program development will consist of eliminating from our mental attitudes the "lazy" philosophy of establishing a quality control program in an area where it is easy to make a good showing. When a company invests the large amount of money that is required to facilitize an automation program, the service-type of organization, such as Quality Control, must adapt itself to the philosophy of providing a service where it is needed rather than where it is convenient to do so. Unless this goal is accomplished, the quality control technician will find himself

in as antiquated a position as the machines which were replaced by automation. The development of a quality control program for automation must be based on the requirements of maintaining an even flow of production. The quality control engineer, or manager, who is interested purely in his own personal success through the use of complicated statistics and elaborate charts, designed to impress non-statisticians, as well as the "inspired" statisticians who are attempting to promote the doctrine of "applied mathematics", will soon find themselves on the wrong side of the fence. Unless the modern quality control technician becomes a definite factor in the day-to-day production problems, his efforts will be as valuable as a nine-cent dime.

Assuming for the moment that the automation program to which we are applying quality control techniques consists of a complete automatization, wherein the direct production, material handling and inspection is performed on a computer-controlled basis, there will be three primary factors which will constitute the quality control program ....receiving inspection,machine capability evaluation and tool control. Since the servo-mechanisms of these machines will perform on the basis of the material which is supplied to the machines, a highly efficient control of receiving inspection must be attained. If the incoming material quality being fed to the machines can be maintained at a reasonably constant level, the amount of in-process scrap and repair will be kept to a minimum. Since the machines will perform the work required on the basis of an established standard, the only other factors which should concern the quality control technician are the kinetic and potential capability of the machines themselves and the productive capability of the tools which these machines consume. For this reason, machine capability studies are of prime importance in the establishment of the overall quality program.

Once the quality level of the incoming material, the material handling equipment and the automated machines has been determined to be constant, the only problem remaining is the establishment of control techniques which will estimate, analyze and predict tool usage. This one factor in itself constitutes the primary reason for the development, during recent years, of Toolometer Boards. Through the use of apparatus such as this the quality control engineer will be able not only to compete with the advances of carbide tools but will be able also to forecast the cost and efficiency of future operations. Under this type of program, the quality control engineer will lose his reputation as a "chart man" and will assume the responsibilities which are clearly defined by his job classification.

Under an automated program, the production operators become, in a sense, patrol inspectors, since their efforts are of the "skilled" labor variety, as opposed to the "unskilled" labor of non-automated operations. For this reason, many of the routine duties which were performed formerly by inspectors and quality control engineers will now be performed by the production operator, due to the close integration of quality with the principles of an automated process.

During recent years, much conversation has been devoted to the idea of replacing men with machines. The member of management who is installing an automation line purely for this purpose will very seldom be around long enough to see his ambitions fulfilled. Automation equipment is not being designed to replace the integrity, loyalty or executive judgement of a businessman. Automation, as a science, is designed only to replace the mistakes and fatigue factors of the average production worker. If the unskilled worker of today will cast aside the antiquated production methods which he respects purely from habit and will develop his mental attitude as fast as he is increasing his standard of living, he will soon discover that the science of automatization represents not only a challenge to his integrity but an opportunity to express his latent talents. In this sense, the production worker will become a true businessman, for it is in his efforts that his company has invested its future profits.

It is wise to observe at this point, that the establishment of an automation program is an expensive endeavor. A company may make a manufacturing process 80% automatic and realize a savings. In attempting to make the same operation 100% automatic, they may lose not only their investment but also their self respect. Regardless of the degree of automation however, any investments in this direction are costly. The cost of equipment and tools represents, in most cases, about 30% of the total cost. As most companies have discovered, almost 70% of the cost of their automation programs is consumed by the problems of plant rearrangement, the training of employees, the cost of engineering changes and the additional space that is required for the numerous conveyors, chip-disposal systems, and storage banks that are required by an automation line. Due to this cost, Cybernetically-controlled machines must be kept running, otherwise they will become obsolete before the amortized cost has been absorbed. If this happens, the problem of developing a quality control program will cease to exist, since many of the smaller companies today could not exist if their investment in automation equipment proves unsuccessful.

As was noted earlier, since improvements in quality and reductions of operating cost constitute the two primary sales features of automation....as well as Quality Control....Quality Control and Automation go hand in hand. Since the success of a quality control program, as well as an automation program, depends largely on the resulting improvements in manufacturing costs, quality control personnel who ignore the advances of automation are making themselves as antiquated as the old-fashioned, non-automatic drill press. As in the case of the production worker, the quality control engineer who fails to discard his outmoded methods is living a short existence in this world of scientific progress.

Keeping in mind the fact that when a customer utilizes his purchasing dollar to acquire a product which he feels is essential to his standard of living, we must recognize the fact that he is not the least bit concerned with the manufacturing methods which the company utilizes to manufacture that product. We, who are responsible however, for those manufacturing methods must never lose sight of the fact that our own personal success depends completely on the successful accomplishment of the investments and programs that are formulated by the top

management of our companies....for it is in them, that many of these same customers have invested their own personal money as stock-holders. Overly-ambitious statisticians and machine designers who fail to recognize this basic principle of industrial progress, constitute the primary bottleneck in developing a sound, hard-hitting quality program that will effectively control an automation process. If the quality control manager, in the development of his quality programs, can successfully adjust his organization and methods to the new demands that are created by the science of automatization, the success and profits of our quality control programs will easily surpass the limited opportunities that have been attained in past years.

Visionary product engineering, improved materials and the science of quality control can then, through the efforts of a qualified quality control technician, attain even greater stature, by producing quality products at a cost which is compatible to our economic future.

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A DYNAMIC QUALITY TRAINING PROGRAM

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Every supervisor on a production line must be constantly aware of the importance of both quality and quantity. The production supervisor comes in daily contact with people who continually remind him of the need for "making his rate", "getting his output", or "making the monthly billing". To compete with the importance of quantity, the production supervisor must be so trained and so stimulated, that his "production mindedness" is always balanced by the quality factor.

To produce a product at breakneck speed only to have it rejected for non-conformance to quality standards by inspection or test ... only sets up a costly sorting mill. The aim and intent of Quality Control is to feed information, as the part is being made, so that the decision to continue to produce, correct the deviation where noted, or shut down the job, can be made during the operation cycle. This immediately raises the questions: "Who takes the readings?", "Who keeps the charts?", "What responsibilities does the production supervisor inherit?".

To answer these questions, the Bendix Radio Division of Bendix Aviation Corporation approached the training of its supervision in the subject of Quality Control as a careful, well planned campaign.

A few of the questions that must be answered by top management are:

(a) In-plant or outside university courses?

(b) Classes during working hours or on "off-hours" of the supervisor?

(c) Theory or application?

(d) An instructor from within the plant or from a nearby university?

(e) Send the supervisors to an established university course or A.S.Q.C. clinic.

The answers to these questions will depend entirely on the speed desired, the availability of university personnel, the locale of the plant and the amount of money the company wishes to invest in a training program.

The answers for the Bendix Radio Division situation were to run the course during working hours in the company classroom under the instructorship of Bendix Radio Division personnel and most important - to teach the course at an operational level.

To stimulate interest, the Bendix Radio Division gadget to demonstrate sampling, a mechanical beadbox called the "Inspectomat", was set up in the plant cafeteria. Provocative signs and a simple straightforward leaflet on the operation of sampling plans was distributed.

Working through the Factory Manager, invitations were issued to a select group of "hard to convince" supervisors to attend Quality Control classes one day a week for a period of one hour over a ten week period. The enrollment was held to a class size of twenty supervisors. The first class was a mixture of men drawn from a variety of dissimilar operations. We were anxious to show that Quality Control would work on job shop or mass assembly lines.

The outline for the course followed along a pattern of "Operational Quality Control". The men had assigned "homework" to go into their job area to gather data for their work studies. The work manual selected was, "A Basic Training Manual on Statistical Quality Control".

The first class meeting found the Factory Manager opening up the session and approximately twenty skeptics sitting in attendance. The early portion of each class was planned to deal with "things they already knew" ... simple examples of variation, a series of repetitive readings forming a trend, etc. With each succeeding class, more and more student participation was encouraged - and at the end, the most eager student was the greatest skeptic in the beginning!

This came about because the classroom material was drawn from their own areas where "they were the experts". The Quality Control technique then became another media through which they could convince other people that action should be taken.

The subject of "who should take the measurements" was resolved by looking at the economics of ... who can gather the necessary information with the least cost and effort. "What shall we record?" was resolved by finding out what were our most costly repetitive problems ... and so it went.

At the conclusion of the first class of twenty, a "graduation" was held with top production supervision presiding and "diplomas" were awarded in a surrounding of joviality, good will and coffee and cake.

The next class was announced and volunteers requested. They came thick and fast but were restricted to the first twenty. From therein, with the limited enrollment per class, no problem existed in securing a quota.

All told, 187 supervisors over a two year period, were exposed to Operation Quality Control.

This training, duly noted on the supervisors' personnel record, was best reflected by the many department walls that

proudly showed a framed Quality Control course diploma.

The greatest single benefit was that more supervisors pitched in to solve the problem through common understanding of the meaning and control of variation. We were fighting the problem - not each other.

Coupled with the completion of the training courses, we have kept the Quality interest alive with Quality posters and with notices of university training courses available, A.S.Q.C. conferences and A.S.Q.C. section meetings. A surprising number of production foremen attend local quality activities.

The investment for the Bendix Radio Division payed off in improved production flow, better supervisory relations between Production, Test and Inspection, but most of all in the constructive suggestions from production supervisors on the solution to many pressing quality problems.

Certificate of Completion

This is to certify that _____ has satisfactorily completed the course on Operational Quality Control, involving ten hours of class-room work and thirty hours of assigned homework, given by the Quality Control Department of Bendix Radio, Division of Bendix Aviation Corporation.

_____
CHIEF ENGINEER,
QUALITY CONTROL DEPARTMENT

_____
INSTRUCTOR

_____
SUPERVISOR OF TRAINING

_____
INSTRUCTOR

_____
DATE

APPLICATIONS DE METHODES DE CONTROLE STATISTIQUE

DANS L'INDUSTRIE CHIMIQUE

J.P. Beaudry
Du Pont Company of Canada Limited

Le contrôle statistique a rencontré ses succès les plus éclatants dans la fabrication de pièces distinctes, où il est facile de spécifier un système d'échantillonnage et de formuler des règles efficaces d'action.

Dans l'industrie chimique nous rencontrons surtout des milieux continus,- liqueurs, solutions, produits chimiques divers - et ici les méthodes statistiques ne sont pas d'application aussi claire et nette. Cependant elles peuvent y trouver leur utilité, et, dans les quelques minutes allouées à ces remarques préliminaires, j'aimerais présenter sommairement les quelques applications qui me sont familières.

Tout d'abord, ces méthodes peuvent être d'une grande utilité au laboratoire de contrôle dans l'analyse de la précision des analystes et des méthodes d'analyse. Un test bien simple et souvent révélateur c'est de dresser un diagramme de fréquence des résultats d'analyse pour un ou plusieurs techniciens. Normalement l'on y trouve une courbe en forme de cloche. Il n'est pas rare, cependant, d'y trouver des fréquences excessives juste en dedans des limites permises, ou spécifications. L'interprétation de tels phénomènes est généralement facile.

L'usage de cartes de contrôle sur la précision et l'exactitude (en anglais, "precision" et "accuracy") des divers techniciens est aussi répandu. La méthode la plus habituelle c'est de prendre au hasard quelques échantillons déjà analysés et de les faire vérifier, soit par le même technicien, soit par un autre; ceci dépend du but à atteindre. La carte de contrôle dressée sur l'intervalle mettra vite en évidence le technicien déficient ou l'appareil défectueux.

Parfois il est nécessaire de comparer périodiquement les analyses obtenues par divers techniciens travaillant sur des équipes différentes, par exemple, pour expliquer un cycle dans les résultats ou pour prévenir de tels cycles. Un test très rapide et très révélateur est dû à J.W. Tuckey et peut être trouvé dans "Transactions, ASQC, 1951". Vu qu'il est d'invention plutôt récente, j'aimerais vous en donner les grandes lignes. Avec les données à l'étude - observations simples ou moyennes - (disons dix au plus par analyste), on construit le tableau suivant:

Technicien	A	B	C	D	Intervalles
	x_1	y_1	z_1	w_1	
	x_2	y_2	z_2	w_2	
	–	–	–	–	
	–	–	–	–	
	x_n	y_n	z_n	w_n	
Totaux	$\sum x$	$\sum y$	$\sum z$	$\sum w$	R_1
Moyennes	$\bar{x}$	$\bar{y}$	$\bar{z}$	$\bar{w}$	R_2
Intervalles Individuelles	r_1	r_2	r_3	r_4	
Différences		g_1	g_2	g_3	

(Les colonnes sont rangées dans l'ordre $x<y<z<w$)

Au moyen des quantités indiquées et de tables appropriées il est possible de déterminer s'il y a écart significatif entre techniciens et, de plus, déterminer quelles sont les différences (g_1, g_2, g_3) significativement élevées. Ce test est évidemment de plus grande portée et peut être employé pour comparaisons rapides de machines, équipes, etc.

Pour conclure j'aimerais dire que l'application de ces méthodes assure le bon fonctionnement du laboratoire de contrôle et peut être une source d'émulation chez le personnel.

Quant aux applications dans l'usine même, la carte de contrôle habituelle est depuis longtemps établie chez nous. Elle sert surtout au contrôle des diverses solutions employées dans nos procédés et au contrôle de la qualité de produits intermédiaires. A propos de telles applications l'expérience nous a enseigné que le succès dépend beaucoup de la disponibilité de moyens rapides d'action lors d'un dérèglement indiqué par la carte. Souvent, cependant, il n'est pas possible d'agir efficacement, soit qu'il n'y ait aucun moyen disponible, soit qu'il y ait retard considérable de l'effet par rapport à l'action corrective. Dans de tels cas la carte de contrôle a peu d'utilité comme outil de contrôle. Elle peut tout de même être d'une certaine utilité en tant qu'indicatrice de cycles, de séquences ou de corrélations avec d'autres variables. L'expérience révèle, aussi, que dans l'industrie chimique, les distributions parfaitement aléatoires sont pratiquement inexistentes et que les cycles, les séquences, les tendances définies y sont toujours plus ou moins présentes. Les règles de la statistique doivent donc être employées avec circonspection et les règles d'action doivent savoir prendre soin de ces cycles et séquences.

Certaines modifications de la carte habituelle sont, aussi, souvent utiles. Il peut être désirable, par exemple, d'indiquer graphiquement les écarts des observations par rapport à la moyenne désirée (ou standard) plutôt que les observations elles-mêmes. Parfois il est préférable de montrer l'écart réduit, $(x-\mu/\sigma)$.

A propos des risques de l'acheteur et du fabriquant je ne puis en parler longuement faute d'expérience, mais j'aimerais attirer votre attention aux nombreuses possibilités qui existent dans ce domaine.

Finalement j'aimerais souligner que la statistique mathématique peut être de grande utilité dans le domaine de la recherche industrielle. De fait ce sont ces applications qui nous sont les plus familieres. J'aimerais m'attarder sur les nombreuses applications du test de "Student", du test de Pearson, de l'analyse de la variance, des études de dépendances statistiques, et au montage de plans d'expérimentation basés sur ces tests; mais ce serait outrepasser le but de ces remarques préliminaires. Cependant j'aimerais exprimer la conviction que la pleine valeur de la statistique mathématique dans l'industrie chimique réside dans ces applications plus générales, le contrôle des fabrications n'étant qu'un cas particulier. De fait nous avons inclus des cours de statistique dans nos programmes d'entraînement non seulement en vue d'applications directes, mais aussi pour développer une attitude réaliste vis-à-vis le travail expérimental et la gérance technique de l'usine en général.

STATISTICAL QUALITY CONTROL METHODS IN THE CHEMICAL INDUSTRY

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Statistical Quality Control has met its most outstanding successes in the manufacture of discrete items - such as machine parts - where sampling schemes and lines of action can be unambiguously specified.

In the chemical industry, where a continuous flow of product is usually met with, the control problems encountered are not quite as amenable to conventional statistical control charts. However, statistical procedures can be of use here and, in the few minutes allotted to these preliminary remarks, I would like to outline some of the applications I have made or have encountered.

Firstly, statistical procedures can be of great value in the Control Laboratory in the study of analyst accuracy and precision.

A simple test and one that can be most revealing is to plot the frequency distribution of the variable under study, for one or more analysts. For a variable under a reasonable state of control a bell-shaped distribution is expected. It is not infrequent, however, to find excessively high frequencies just within control or specification limits. The interpretation of such results is usually quite easy.

The maintenance of control charts on analysts' precision and relative accuracy is another frequent application. A suitable scheme is to keep random samples and have them re-analyzed either by the same analyst or by a different analyst depending on the purpose in mind. Control charts on the averages and ranges for these duplicate results are then readily set up and interpreted.

Sometimes a periodic check on the relative accuracy (or bias) of certain analysts compared with others doing the same work is required. For instance, it may be desirable to compare shifts. A quick and most helpful test has been worked out by J.W. Tuckey and may be found in the Transactions, ASQC Convention, 1951. Since you may not be familiar with this method I would like to outline it here for you.

Individual results or daily or weekly averages (up to, say, 10 per analyst) are tabulated as follows, in order of increasing averages:

Analyst	A	B	C	D	Range
	x_1	y_1	z_1	w_1	
	x_2	y_2	z_2	w_2	
	x_n	y_n	z_n	w_n	
Analyst Average	$\bar{x}$	$\bar{y}$	$\bar{z}$	$\bar{w}$	R_1
Analyst Total	$\sum x$	$\sum y$	$\sum z$	$\sum w$	R_2
" Range	r_1	r_2	r_3	r_4	
Gaps between Totals		g_1	g_2	g_3	

(Sum of Analyst ranges = $\sum r_i$)

By means of suitable tables and the ranges shown above, it is possible to determine whether R_2 is significantly large and also which of the gaps are significantly large.

The method, of course, is of broad application and can be used in the plant to compare such units as machines or shifts.

In conclusion I would like to say that the use of such methods are not only helpful in detecting abnormal conditions but can be a healthy stimulus to laboratory personnel.

In regard to plant applications, we have for some time made use of the conventional type of chart for the control of process liquors and of the quality of intermediate products. In the application of such charts it has been our experience that success is very much dependent on the existence of quick methods of correction of off-standard conditions. Too often, however, it is not possible to take effective action either because there are no physical means of doing so or because of a considerable time lag between the action and the resultant effect. In such cases the control chart is of little use as a tool for control. It may still, however, be of some use in showing long term trends or correlation with other variables.

It has also been our experience that the true random distribution is a scarcity in the chemical industry and that runs, trends and cycles are predominant. The usual rules of statistics must therefore be applied with discretion and rules of action must be designed to take care of runs and trends.

Variations from the conventional chart have also proven useful. In certain cases it may be desirable to plot deviation from standard rather than the actual observation, or, where the standard deviation as well as the standard average change, the ratio of the deviation from standard to the standard deviation may be plotted.

In regard to control of producer and consumer risk I have little experience to speak about. However, I would like to draw your attention to the possibilities that exist in this field.

Finally I would like to mention that Statistical Methods can be a great value to the chemical industry in research and development and it is with this type of application that I am most familiar. I would like to draw your attention to the many uses of Student's t-test, Pearson's Chi-Square test, correlation analysis, analysis of variance and to experimental designs based on such tests. As a matter of fact, it is my conviction that Statistical Methods should be considered from this broader viewpoint with Quality Control a particular application. With these thoughts in mind we have, at our plant, made it a point to train personnel into the understanding of Statistical Methods not only with a view to specific application but also to develop a more realistic attitude toward experimental work and plant control in general.

BASIC CONCEPTS APPLICABLE TO BREWING

Brant Bonner
University of Western Ontario

Statistical quality control procedures had their early application in the metal working and assembly industries, but the techniques have since found wide acceptance in other fields. The brewing industry has been a beneficiary as well, as may be attested by the numerous successful applications which have been made.

To the average concern, substantial benefits are achieved through reduced inspection and less scrap and rework, considerations which can readily be evaluated in terms of cost savings. However, in only limited instances can direct cost savings accrue from a brewery program at the outset. The brewer does not have a problem of scrap and rework, except in a minor way; being the producer of a food product, he is faced with the necessity of striving for a 100% quality level, and even though his bottle inspection system leaves much to be desired, he does not feel he can accept the risks which are inherent in inspecting on a sampling basis.

The brewing company then, must approach the question of adopting statistical control procedures more from the standpoint of product quality improvement than from that of cost savings. In time, the quality improvement should mean financial gain - a closer control of air and CO_2 content and a higher level of package quality, for example, will put the company in a better competitive position.

As the program develops there will be opportunities to reduce costs. For example, a brewery which has had both empty-bottle and full-bottle inspection may find that with an effective control system established for bottle examination, better results can be attained under the new system with full-bottle examination alone than was achieved formerly under the double examination.

Brewers have always kept close tab on quality as may be evidenced by numerous laboratory checks, frequent taste panel sessions and detailed brewhouse reports, and as a result may feel hesitant to make any change. Actually, however, the adoption of statistical quality control methods does not mean any basic change in control procedures. What is involved is the providing of additional information on which to base decisions, information which is gained through statistical analysis. For example, with such an approach, the bottle shop superintendent could know from day to day, or from crew to crew, the quality level of the out-going package and would not have to rely on the nebulous factor of customer complaint. Further, having the information on a current basis, he can take any necessary corrective action, something which may not be possible if there is a time lag of a month or so.

With well established quality control procedures already extant in a brewery, statistical techniques can be introduced with a minimum expenditure of time and funds. As the program is expanded, more will be involved of course, but by such time management will have had an opportunity of evaluating the accomplishments to date.

The success experienced in using SQC techniques has encouraged

industry to look with interest to other statistical procedures, and those which have been adopted usually come under the same general heading. Whatever the subsequent additions, statistical quality control is basically concerned with the problem of variation - the variation which exists in all production and in human endeavor.

The first step in establishing statistical control is to determine what the variation is. In some instances the information is readily available in existing records, in other situations, the information will have to be collected directly.

Following recording the data in a table or quality control work-sheet, they are then plotted in a chart, which provides an over-all picture and permits discerning any patterns and trends which may be present in the data.

The next step is analysis of the variation found. That for which a reason can be cited is referred to as variation arising from an assignable cause, and it can be eliminated; better inspection lighting should help to reduce variation in bottle examination work - a proper selection of clerical people should result in fewer mistakes being made.

The variation remaining after all variation arising from assignable causes has been eliminated is that which is inherent in the process. It must be tolerated unless the company is prepared to secure new equipment, use better material or the like.

With the assignable causes of variation eliminated, control limits are fitted to the residual variation. These limits indicate the range within which future observations or sample averages should fall if no assignable causes of variation enter the process. The control limits acknowledge the inherent variation in the process and focus attention on any situation which may develop and should be corrected. The brew-house foreman noticing that his kettle yield is falling below what it should be, may want to have the setting of the malt mill checked, among other things.

This type of analysis can be applied to many situations in the brewhouse and bottle shop as subsequent papers will indicate. It can also be used in plant accident control, in sales analysis, in fore-casting, and so on - wherever there is variation.

Statistical control can be used to assure that the quality of incoming material is at a satisfactory level. In establishing what are satisfactory quality levels, one may be obliged to study the product or the use for which it is meant, and in this rather detailed approach, valuable information is often gained which can contribute to a better operation or a more economical purchase of supplies.

Statistical quality control offers some relatively simple tools for analyzing problems which may occur in brewhouse or bottle shop operations, tools which can be used effectively by operating personnel as well as management, if the basic concepts are understood. It is essential then, that all concerned with the program learn of the methods and objectives of SQC.

INTEGRATED QUALITY CONTROL FROM WEAVING TO SEWING

Fred Golden
United Merchants & Manufacturers, Inc.

Marquisette cloth made by our new weaving mill was first quality cloth measured by rigid 100% inspection standards. It went to our separate finishing plant where every yard was inspected before shipment to our curtain factory nearby.

There were some costly cut-outs of defects at the cutting table, but for curtains the out-going quality level, judged by our detailed sampling control plan, showed a reassuring low percentage of defects.

Each plant was sure it had top quality---each used some of the latest techniques for inspection, grading and quality control. Still, a major customer complained that our percentage defective was too high, even though it was better than other suppliers.

The customer bounced quantities of curtains back to us from its various stores and warehouse receiving points. But when his chief quality control man re-inspected some of the returns, neither he nor we could find reasons for rejection in many cases. Returns from the stores' customers were infrequent. Other customers of ours rejected few curtains.

How could each organization prove it was so right---and yet be wrong? Well, it's like the little boy running around one of those summer camps on the usual round of activity. His tiny trunks were half way down his hips, and on their way off altogether. A visitor, hoping to avoid what he viewed a potential mishap, shouted, "Hey, little boy, you're going to lose your trunks." The unruffled little boy casually replied, "Oh no, my mother sewed my name in everything."

Now this little boy was looking at things differently than the guy who shouted the warning. And both were right. As a matter of fact, those of you who didn't enjoy this little story probably had different specifications for an amusing story than I do. In that case, if my main purpose was to make you laugh, I had better find out first what your idea of a good story is!

A common point-of-view on the quality of curtains acceptable by the final customer, was a missing element in our situation.

Also missing were agreed upon definitions of visual factors such as workmanship and cloth appearance, - and the communication of this elusive information to everyone concerned with both the sale and manufacture of the finished product. We did not have guages to measure our quality, as so many metal work plants do.

Also, those cloth characteristics which make sewing easier (and quality harder to maintain) were not brought to the attention of the weaving and finishing plants. The fact is, even within the sewing plant, inspectors, foremen, operators, management and sales personnel did not all have a common agreement on quality points.

And a major customer's buyer, his chief inspector, and the various

inspectors at their receiving points did not all have the same definition of quality.

Some examples pointing to these missing elements:

Bowing in the cloth not noticeable enough to the weaving mill to classify as defective, kept the curtains from hanging straight when they were put up on a window.

Minor imperfections in the cloth spread out over thousands of yards, and point graded as top quality, can look a lot different when you gaze at 6 yards of material over a window with the sun pouring through.

Bias on white marquisettes may not be noticeable or important to a finishing plant inspector, but in the sewing plant bias can cut production drastically, increasing seconds and rejects.

An inspector in a store, not knowing that perfect cloth is impossible, may reject every curtain with a flaw even if the final customer - the housewife - doesn't object, and expects some imperfections.

A buyer may demand that all curtains be 100% perfect, but he may not want to pay the cost to accomplish this.

We can see that what may add up to 1st quality cloth in a weaving mill, a finishing plant, and the sewing plant using these goods, may not be the <u>right</u> quality required by the final customer.

The end use of the cloth makes a big difference to quality control!

To a large extent, correct quality depends upon the specifications.

A first step in quality control then, must be to define the specification for the end use that the product is to have, within cost and technical limitations.

And the next step must be good communication and acceptance of these at all levels responsible for quality. This is a key requirement where visual factors are involved.

Otherwise, companies are going to end up with some beautiful quality controls that may work perfectly---but turn out the wrong quality that doesn't do the job, or does the job too expensively.

No matter what part of the operation you do yourself, it is necessary to integrate quality from yarn to final product.

This principle of directing quality toward the finished product applies to all industries; if you make metal parts for another manufacturer building motors for a machine tool, you must keep the performance of the machine tool in mind.

STEPS TAKEN TO INTEGRATE QUALITY CONTROL

Here, in outline, are some of the steps we took to integrate our quality control from the weaving mill - to sewing plant - and to the customer. A few of the forms designed for the sewing plant are also included.

1) Major customer defined his specifications. Particular attention given to those factors judged by visual inspection, such as workmanship and cloth defects.

   a) Visit by customers' quality control supervisor to review returns, rejects, and curtains accepted by our sampling inspectors.

      This man held discussions with our inspectors and supervisors. These discussions enabled our personnel to "play back" the instructions on how to inspect, to make sure that there was a meeting of the minds between the customer and our personnel on each quality point. This was particularly important where degree of defect was involved.

   b) Customer prepared booklet with pictures showing rejectable and non-rejectable defects, with limitations on each (Exhibit I). We are still debating and revising some of these, to clear up questionable points. In some instances to eliminate all of the defects would be uneconomical, so revision of the standards was required.

   c) Analysis of inspection reports made by customers receiving inspectors. In some instances we found that returns were not justified. As a result further communication of customers' specifications to individual store and warehouse inspectors was made by our customers' central quality control department.

   d) Set up the concept of rejectable and non-rejectable defects. A certain number of non-rejectable defects are required before the curtain is returned by the customer, or classified as rejectable by our inspectors. This cut down the area of question and reduced the number of curtains returned unnecessarily by our customers for minor imperfections.

2) Assigned industrial engineer responsibility for quality control in sewing plant.

3) Set up random sampling inspection of each type of curtain.

   a) Maintained statistical quality control charts on results, by each type of cloth and each style.

   b) Inspection form describes each possible defect to be looked for (Exhibit II).

4) Re-trained supervisors and operators on the above specifications

   a) Closely watched work of each inspector to make sure specifications were communicated to them.

b) Checked qualifications of all inspectors. Formerly, the best production workers had been selected as inspectors. This was not necessarily the best qualification for becoming an inspector.

c) All inspectors were taken off piece rates. (This may be debatable as a quality point, since we know that some companies successfully use piece rates on inspection operation.)

5) Traced defects to each operator quickly by having in-process inspectors prepare check lists on each curtain they inspected. (Exhibit III.)

a) Check list maintained by type and by operator.

b) Inspectors located at key points in the production line.

c) Previously no record was kept by the in-process inspectors, so that it was not apparent to the supervisors which operators were turning out defective work consistently.

6) Set up a system of numbered work orders to give to mechanics from quality control section when machines apparently were causing rejects. (Exhibit IV.)

a) The written reports from in-process inspection frequently brought mechanical troubles to attention.

b) Written records of difficulties pointed to cloth problems correctable by finishing and weaving plants. Without these records complaints previously went unheeded or unproved, in many cases.

c) Consistent patterns of defects often pinned down the exact mechanical cause on a machine making defects.

d) The numbered work orders provided a means of follow-up by the quality control section for corrective action.

e) Led to new jigs and equipment that permanently improved quality.

7) Analyzed all returns from customers.

a) Charted type of defect.

b) Charted percentage of defects. Cumulative units as a percentage of cumulative production.

8) Eliminated repair operators and required piece workers to do their own repairs.

9) Set up red, yellow and green signals. When in-process inspection report showed a consistent pattern of defects, the operation would be stopped completely in order to correct the problem. A yellow signal would indicate a problem on its way out of control.

a) This added impact to our emphasis on quality.

10. Emphasized quality in all training work and set up posters to make employees more quality conscious.

a) Added pride in work as another incentive to foreman. Previously foreman got greater satisfaction in reporting the number of units produced.

11. Sampling inspection at curtain factory on all incoming cloth.

a) This was done when cloth was received. Previously, the only inspection was done as goods were cut.

b) Set up control charts for each fabric.

c) Kept an inspection report on each cloth as a result of the sampling inspection. (Exhibit V.)

12. Set up a definite procedure for handling defective pieces and cut-outs.

a) Previously the cutter exercised his own judgement on this. We narrowed this down so that he knows when to cut out defects, how to make use of some of the shorter panels resulting from cut-outs, and when to reject the lot.

b) When cut-outs are excessive they are checked by the manager.

c) Showed cutter rejectable defects he passed.

13. FINISHING PLANT APPOINTED QUALITY CONTROL MANAGER TO SERVE AS LIAISON WITH CURTAIN FACTORY AND WEAVING MILL. TRACKS DOWN CAUSES OF REJECTED CLOTH, OR CLOTH CAUSING SEWING PROBLEMS.

a) This was one of the most important steps taken because it was largely through this man's work that corrective action was accomplished, as far as cloth problems are concerned.

b) Finishing plant continued 100% inspection of cloth.

c) Immediately investigates complaints or problems found by sewing plant by going directly to the sewing plant.

d) Tries correction at finishing plant or traces causes to weaving mills and visits mill to help solve problem.

e) This provides a permanent two way communication so that disagreements are held to a minimum. Problems are taken more in stride, on a routine basis.

14. WEAVING MILL ASSIGNED INDUSTRIAL ENGINEER-QUALITY CONTROL HEAD TO VISIT CURTAIN FACTORY AND WORK WITH FINISHING PLANT LIAISON QUALITY CONTROL MAN.

a) To track down causes of rejects or extra costs incurred by the curtain factory and customer.

b) Visits finishing plant and sewing plant to help solve problems created by weaving.

c) Continued extensive quality control point grading system for all finished cloth. This system includes cloth quality reports; daily seconds and defect reports by types of defect; analysis of seconds, with reports sent back immediately to the weave room on any second; and a sampling check of the graders.

d) Intensified quality checks of incoming yarn, including sampling for strength, eveness, denier, etc.

15. Acquainted plant managers of finishing and weaving mills with the requirements of the finished curtains. This oriented their thinking more along the lines of a "curtain man," as far as certain cloth problems are concerned.

a) Had each manager meet with the major customers' quality control manager.

b) Showed them customer complaints.

16. Sewing plant quality control manager prepared written summary of results to top management each month.

EXAMPLES:

Let's look at some of the examples of what our integrated quality control program accomplished, which might not have been done without an integrated approach:

1) There was bowing in the cloth, which wasn't noticeable enough for the weaving mill to classify as defective. When the curtains were hung, they wouldn't hang straight. When the weaving mill saw the finished curtains that didn't hang straight, the mill went to work to eliminate the problem.

2) Dacron cloth coming from the finishing plant seemed to meet all required standards. Yet, we found that the curtains were fraying easily in handling and sewing. We found that the cloth was in tolerance for the hand standard, but the hand was on the soft side. By setting a firmer hand---in other words setting a specification geared to meeting this sewing problem--the problem was eliminated.

3) Our major customers' inspectors were rejecting considerable quantities of curtains because the length of one side was not in tolerance. When shown that with one side in tolerance, and the other out only slightly, that the curtains could be hung evenly, the quality control man agreed the curtains should not have been returned.

Even so, we decided to class these as minor defects and trace back the causes. We revised cutting methods to control lengths better. Working further back, the finishing plant watched the bowing that partly caused this problem, and rejected cloth or advised weaving as soon as the bowing was discovered at the

finishing plant--even though bowing was no problem or obvious defect to the finishing plant or weaving mill.

4) One of our major customers set up a check list of reasons for returns, detailing certain fabric defects such as dirt and grease, holes, etc. Then, it had one big category "workmanship" and another "appearance." What item of workmanship or appearance was involved was not clear. As a result, the sewing plant looked and looked and could find nothing wrong as far as their standards were concerned. In some cases, neither could the quality control department or the customer. Better definition corrected this.

5) Some of the stores were sending back curtains with slight defects which were not rejectable defects. It was necessary to communicate the specifications back to the store inspectors.

6) Too many fibreglass curtains were being returned. This is a cloth which by its nature is more easily damaged in weaving, finished sewing and--handling by the stores. A new and better finish helped improve the process, but it was necessary to set up separate standards for this type of cloth. End result--- fewer returns, better handling by customer.

7) The sewing plant foreman used to check the work of individual operators by picking up some curtains and looking them over every once in a while. No records were kept.

The foreman soon discovered that they did not really have the control over quality the way they thought they did by this casual checking. Our control program showed foremen what was out of control very soon after the condition occurred.

8) The sewing plant found that when operators were sewing low count nylon cloth, they were getting over-hanging on the bottom hems and the rod hems, and were having a difficult time controlling this cloth, as compared with others.

By increasing the tension on the hem while sewing, operators got puckering in the hem, and by regular tension or lessening of it, they got over-hanging.

This cloth had a much firmer hand for a standard, compared to the higher count nylon. Consequently, it had less give and was harder to control. It was found that much of this nylon was being received with a hand on the firm side of the standard.

A softer hand standard was established and the finish was kept on the softer side without getting slippage in meeting the wash test. Also, the cloth with firmer hand was used on a few machines at a slower speed, until the hand was softened to the standard. Some cloth with very firm hand was sent back and refinished.

You can see from this example, as far as the finishing plant quality is concerned, finishing was well within the tolerance. What was necessary here was the point of view of the sewing plant, which in the final analysis required a change in the

specifications for hand.

We can also see from this example the saving in cost to perform the sewing operation, which was reflected at the same time that a quality problem was eased.

9) One of our out-of-control reports showed that miracle hem cloth sewn on all automatic side hemmers was ending up with bad side hems. We found that the automatic feed worm which aligns the cloth was not holding the alignment. Nothing was wrong with the worm or the electric eye which controlled it. We discovered that miracle hem alignment requirements were too difficult to control on existing automatic feed, and the losses would run high continuously, compared to other cloths.

Action taken was to develop a new control of the feed, to hold the tolerances. The problem was solved in a matter of days, since the problem was recognized in time.

a) Through quality control a new machine control was installed for use on other cloths; that resulted in a reduction in losses on other cloths which were not actually out of control.

To summarize some of the end results we achieved:

1) Customers' satisfaction, and substantial reduction in returns by customers.

2) Lower labor costs in the sewing plant and in finishing.

3) Substantial reduction in cloth cutting losses due to cut-outs of defects.

4) Reduction of seconds found in process.

5) Out-going quality level as measured by random sampling showed a consistently reduced upper control limit.

6) Reduced repairs and rework.

7) Lower labor costs for quality control, resulting from reduction of returns, repairs, etc.

8) Reduction of internal differences of opinion.

CONCLUSIONS:

Some of the key points which can be drawn from our experience and applied to textile and other industries:

1) What is to be controlled should be a step before how you are to control it. Many of the well developed quality control techniques such as control charts, sampling inspection, and similar plans can be made to work right, controlling the wrong attributes.

   So, before setting up statistical controls, carefully define each attribute.

   To do this requires coordination throughout all plants involved. This applies to companies supplying parts to non-integrated companies. For example, an independent weaver must establish quality standards in terms of finishing and the final article using the cloth.

2) Make sure that quality specifications are understood all the way down the line - and across the line to the customer. When these factors depend upon visual inspection, they are all the more essential---and more easily lost sight of. More than likely, visual factors now are taken for granted.

   Our experience just described shows some ways these visual factors can be pinned down and communicated. Even so, we have another step to take---determining what the housewife wants.

3) For those in the sewing industry, our experience proves that control charts and acceptance sampling plans, which have had such wide-spread use in other industries, do work in sewing plants too.

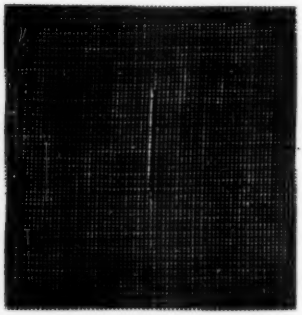


Figure 14

BROKEN END - Actual Size
Reject--Never acceptable.

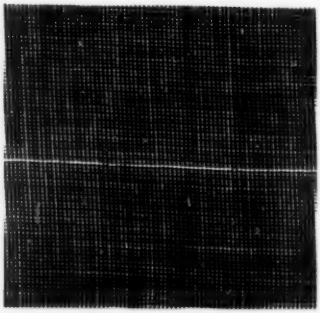


Figure 16

HEAVY THREAD - Actual Size
Acceptable - In important area of curtain--limit this type of imperfection to one to each side of a pair across width. Not more than 1/3 length of curtain.

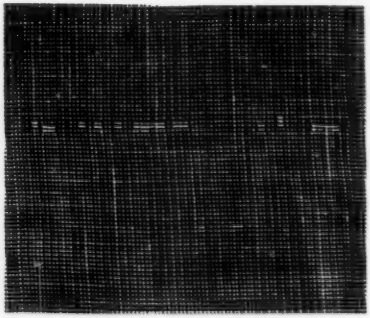


Figure 15
BUTTERFLIES - Actual Size
Accept in semi-important and inconspicuous area.

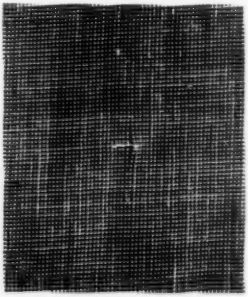
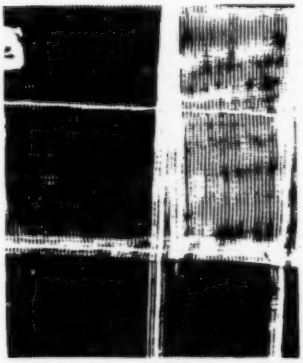


Figure 17

SMALL KNOT - Actual Size
Acceptable - In important area limit this type of imperfection to two to each side of pair.

E. WORKMANSHIP DEFECTS - Continued



ROD AND BOTTOM HEM OVERLAP
Allow up to 1/4" overlap on any fabric.

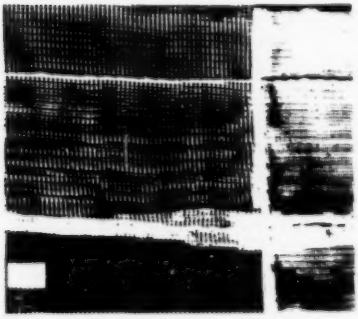
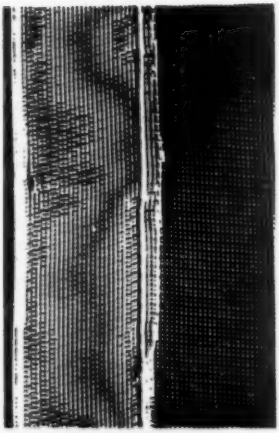


Fig. 47
SPREAD HEM
Acceptable if there is no raw hem.



RAW EDGE - Reject always

EXHIBIT II

FINAL INSPECTION OF TAILORED CURTAINS		DATE: _____ BOX NO: _____ MATERIAL _____ TIME: _____ STYLE: _____ INSPECTOR'S NO: _____	No of defects per box
	INSPECTIONS		
EXAMINE ENTIRE BOX FOR:	1 Curtains neatly placed in box		
	2. Curtains properly fit in box		
	3. Proper fit of hood		
	4. Correct quantities in box		
		CURTAIN NO. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	Rej Rej.
EXAMINE EACH CURTAIN FOR:	5. Are Curtains placed neatly in box		
	6 Does label correctly identify Curtain		
	7. Does label agree with hood and/or box		
	8 Is label sewn neatly		
	9 Are Curtains properly fri ed		
EXAMINE HOD HEM FOR:	10. Thread mismatched — Rejectable / Non-rejectable		
	11 Square corners — ejectable / Non-rejectable		
	12. Ends closed		
	13. Raw edges — Rejectable / Non rejectable		
	14. Evenness of hem		
	15 Stitching loose		
	16. Stitching tight		
	17 Stitching skip		
	18. Proper hooks used		
EXAMINE BOTTOM HEM FOR:	19. Thread mismatched — Rejectable / Non-rejectable		
	20. Square corners — ejectable / Non-rejectable		
	21. Ends closed		
	22. Raw edges — ejectable / Non rejectable		
	23. Evenness of hem		
	24 Stitching loose		
	25. Stitching tight		
	26. Stitching skip		
	27. Proper hooks used		
EXAMINE SIDE HE FOR:	28. Square corne		
	29 Raw edges — Rejectable / Non-rejectable		
	30 Stitching loose		
	31. Stitching tight		
	32. Stitching skip		
EXAMINE FOR CLOTH DEFECTS	33. Holes		
	34. Rinsmarks — Rejectable / Non rejectable		
	35. Dirty		
	36. Oil stains		
	37 (Overall length — Rejectable / Non-rejectable		
	38 (Overall width — Rejectable / Non-rejectable		
	TOTAL REJECTABLE DEFECTS		
	TOTAL NON-REJECTABLE DEFECTS		

EXHIBIT III

QUALITY CONTROL--[illegible]

Date_____

Name & No. _____

_____

R--Repairs

S--Seconds

Total Inspected_____

CAUSE OF DEFECTS		R	S	R	S	R	S	R	S	F	S	F	S	R	S	R	TOTAL I	R	S
1. Workmanship	Cloth																		
	Ass.																		
2. Lengths	Cloth																		
	Ass.																		
3. Sleeves	Cloth																		
	Ass.																		
4. Frays	Cloth																		
	Ass.																		
5. Holes	Cloth																		
	Ass.																		
6. Dirt	Cloth																		
	Ass.																		
7. Oil	Cloth																		
	Ass.																		
8. Rust	Cloth																		
	Ass.																		
	Cloth																		
	Ass.																		
	Cloth																		
	Ass.																		
SOURCE OF DEFECTS																			
1. Roll Hips	Cloth / Ass.																		
2. Hook Run	Cloth / Ass.																		
3. Jetting	Cloth / Ass.																		
4. Ruffle	Cloth / Ass.																		
5. T.P.T.	Cloth / Ass.																		
6. Overlock	Cloth / Ass.																		
7. Tieback	Cloth / Ass.																		
	Cloth / Ass.																		
	Cloth / Ass.																		

EXHIBIT IV

QUALITY CONTROL

Project # _____ Project Name _____ Date Assigned: _____

Assigned To: _____ Approved By: _____

Cause of Defect _____

Source of Defect _____

Cloth Nos _____ Mach Type & No. _____ Clock # _____

Repairs _____ Seconds _____ % Repairs _____ % Seconds _____

Description of Defect:

Date of Cause & Source:

Recommended Action:

Progress & Remarks:

Date Completed _____ Signature _____

QUALITY CONTROL CLOTH INSPECTION REPORT

Date: _____ Ave. Length/Panel _____ Name: _____

Cloth # _____ Style _____ Color _____ Source: _____

Case #'s Rec'd _____ Yds Allocated _____

Ydgs. Rec'd _____ Yds. Inspected _____

Case #'s Inspected _____

YARDAGES					DEFECTS							
Range	Diff	Defects	Ave.	Panel Potential	Holes	Frays	Miscuts	Oil	Stains	Bids	Snags	

Certain Loss

Theoretic. Panels: _____

Panel Potential: _____

% Panel Potential: _____

% - " - Loss: _____

Yardage Loss

Yardage Total: _____

Ydg. Defects: _____

- " - Allocated: _____

% Cloth Loss: _____

Occurance of Defects

Occurance: _____

Aver. Defect: _____ Yds

EXHIBIT IX

COMPANY WIDE QUALITY CONTROL TRAINING

F. Bruce May
Johnson & Johnson

Training for Quality Control is a continuing thing. It cannot be done in one session. For full effect and lasting results, the need must be created, then the training must be continued over a long enough period of time so that all of its ramifications are understood. Some of the training must be formal, but most of it should be informal. That is, it should be on the spur of the moment bringing the need and accomplishments subtly into conversations and meetings. The need for formal training at top management levels usually is approached from within more effectively from an informal point of view.

To do this, it is important to build in the minds of top management the need for some kind of control different from what already exists. This might be done by very pointedly bringing to management's attention the existence of confusion because of a lack of specifications. It should, of course, be pointed out that much is to be gained by better specifications. With this introduction, an opening is made for a discussion of Quality Control techniques in conjunction with the specifications, for naturally it would be wasteful to have good standards and no measurement of conformance or control based on them.

Another procedure would be to show non-conformance to existing specifications. It has been found that in most areas where specifications do exist and no good formal control plan is in force, that the specifications are used more as guides rather than specific operating criterion. The fact that variations from specification are allowed implies that either the Manufacturing Department, or the Control Department is taking it upon themselves to make decisions concerning non-conformance of product to specifications. This not only breeds confusion regarding acceptance of the responsibility for product conformance, but also places in the hands of the wrong parties this responsibility. In pointing out this non-conformance to specification, it opens the way for discussing means of attaining conformance.

Another method of interesting top management in Quality Control techniques is to jingle the loud sound of savings in their ear. This can be done by choosing a problem or a number of problems, working them out, and making specific reports pointing out the procedures used, as well as the savings accomplished. It might also be possible to inveigle top management personnel to attend Quality Control Conferences in which appreciation discussions are given.

With your foot in the door, or with an interest created in the top management group, what is the next step? It is important to show these people that there is some scientific basis behind Quality Control. This may be done by going through a simple demonstration of a Quality Control technique. A warning should be given here. The demonstration should be simple, but not too simple, since it is possible that the Executive might get the idea that the results are obvious and might be obtained through little or no training on the part of the person applying the control, or that better control can be obtained simply by applying pressure.

Most importantly, tell the top management people something that

will amaze them. Preferably some problems that they may be causing as a result of unscientific approaches to quality improvement. The best way to accomplish this is to use a quincunx and normal distribution board explaining the scientific background for the $\bar{X}$ and R chart. Then feed them as a parting shot the fact that if process capabilities are not measured that it is possible to increase instead of decrease the outgoing quality variation. This, it should be pointed out, will happen despite the fact that the supervisor is attempting to reduce the variation in the process. He will be making adjustments in an attempt to hold the process to tighter limits when samples fall outside a given limit. In actuality, he may be increasing the spread by continually changing the settings. Usually leaving this sort of idea in the Executive's mind will at least make him consider the possibility of giving Quality Control techniques a try.

With the opportunity to install a Quality Control program, training at top levels is not finished. It is only started. The training, however, from this point on may be done more informally. Unless there are specific requests for further information concerning the scientific background or Quality Control techniques, the training then is done through reports indicating what progress is being made in establishing a good Quality Control program.

Actually this is getting a little ahead of the story. The first step is to work out with the Executive group goals that are to be attained. These goals may be the extent of Quality Control coverage anticipated, dollars saved, quality improvements made, etc. Of course, at the same time that the goals are established, methods or procedures for measuring progress against these goals should be devised and reports should be planned so that they drive home the improvements as they are made. Cooperation for preparing these reports may come from the Cost Department, Production Department or the Complaint Analysis group.

One extremely interesting device that we in Johnson & Johnson have recently started is the establishment of a quality level standard, and the measurement of the variance from this standard each month. The Manufacturing Department establishes its own standard in a similar fashion to that of establishing a cost standard. Variations from the standard are then measured and plotted on a very simple report that is published monthly.

On either a quarterly or six-monthly basis, the achievements should be reviewed against the existing goals, and the goals should be re-established or revised.

With the production supervisor, the amount of training in the application of Quality Control techniques should be much greater. Production supervisors should know fully what the tools of Quality Control are capable of doing for him. It isn't necessary for the production supervisor to actually be able to use the Quality Control tools, but he must have enough knowledge of their application so that he may know what to expect, and may make requests as to where they can be applied. Here again, to obtain the interest of the production supervisor is just as important a factor as it is with the Executive. The easiest way is to start off with the top manufacturing man and convince

him, along with the Executive group, so that you may obtain an invitation to present your inspirational talk at his staff meeting. This will provide an opportunity for the production supervisors under him to know what can be accomplished with the application of the easily explained tools of Quality Control. Here again, the quincunx is one of the most important demonstration media that can be used.

If there have been some problems worked out by Quality Control techniques in the supervisor's manufacturing department, then these also should be used as samples of how Quality Control functions and what it can do. Once the production supervisors interest is obtained, a course in Quality Control applications should be given to them.

For this training, it would be well to have a person from an outside quality department prepare and give the lectures using examples that were taken from the department receiving the training. The production supervisors should be encouraged to bring in their problems. With the Quality Control supervisor of that area, data should be collected so that those problems can be solved in the classes.

Here again, simple demonstration devices such as the Shewhart Bowl, sampling beads, control charts and so forth should be used extensively. While actual calculation should be done in class, it is important to keep the arithmetic simple and keep away from the more complicated aspects of the applications of the techniques. If some of the problems that are brought to class look particularly knotty, it might be best to solve them outside of class, and then present the solutions in a simplified form at the next session.

Where the manufacturing supervisory trainees are college graduates, they can be thrown in with the Engineers, Quality Control Supervisors, and Research people in a complete training program that is very much similar to a two-semester course that might be given in a university. The first-semester portion might cover the basic Quality Control techniques, and the second semester, the analysis of data touching on the elements of design of experiment. For Quality Control, Engineering and Research people, depending upon the progress that has been made in the company, and the acceptance of such techniques, it might be possible that an extended course on the design of experiments might be offered.

Here again, training is not over once the formal courses are given. It is important that quality committees be established and that these committees establish the goals, methods of measurement and so forth that suggest problems to be worked upon, study results and marshal information to be presented to the Executive group. The Quality Control man who leads the discussion in these meetings, may wish to review at times some Quality Control techniques for the benefit of those people on the committee. This training is usually done by the use of examples, only calling on the demonstration gimmicks where necessary.

Quality Control inspectors should have training in the aim and responsibilities; the basic techniques and arithmetic of Quality Control; and how to conduct themselves to obtain cooperation and action. For best results, these courses should be taught by the Quality Control inspector's supervisor, taking specific examples out of their everyday operation. Numerous examples should be worked out in class to give

them the confidence of being able to apply what is being taught.

This very briefly is the gist of company wide training for Quality Control. As in any sales job, the results are consistent with the enthusiasm of the salesman. The only way that full enthusiasm can be developed is through actual successful application of Quality Control techniques. Many people shake their heads in approval of the techniques upon hearing about them, but few people remain calm after having seen, at first hand, their power in achieving improvements.

HOW TO GET THE MOST OUT OF A QUALITY CONTROL BUDGET

Kenton R. Willhite
North American Aviation, Inc.

One of the easiest things to do is spend money. The results of spending more money than we make are often embarrassing if not disastrous. This is just as true of businesses as it is of individuals. The proper use of money is, therefore, one of the most complex and important functions of business management.

Answers to the question, "How to Get the Most Out of a Quality Control Budget," must be in terms of the efficient utilization of money by quality control management. Many budgeting problems are imbedded in such things as company organization, financial structure, company policy, type of product, competition and other abstract issues. Some answers to the question can be obtained, however, through logical analysis of the general aspects of the budget problem.

In most aircraft companies inspection and quality control are considered as an overhead, or burden function. Much of this thinking is historical in nature. In other words, it is that way because it has always been that way. This is a disadvantage, to a greater or lesser degree depending on the management view of the quality control effort. Many functions performed by the aircraft quality control people are necessary under MIL Q 5923B, or other contractual requirements. For this reason portions of the quality control effort could be considered as direct labor. Two separate studies have been conducted at North American in order to plan along this line. These studies indicate that more than 80% of the total quality control labor effort could be charged to direct labor. We feel that this would be advantageous and intend to continue our efforts toward this goal. However, it must be realized the allocation of quality control effort to direct labor will not reduce the total cost of the product. The primary benefit is in the reduction of the total company overhead rate.

In some companies it is practice for management to establish budget limits. In other words, the various elements of the organization are told that their costs cannot exceed a certain sum. This is not true at North American Aviation. The Quality Control Division determines the amount of money required for its operations. This data is submitted monthly to the financial division for inclusion in the total budget. In either case, the same type of budget control and evaluation is necessary to keep costs within proper limits.

Three facts regarding the quality control budget are readily available: (1) The problem is complex; (2) The answers to the problem require analysis of functions other than quality control; (3) The solutions to the problem are primarily in the management area.

Before we can determine how to get the most out of a budget, it is necessary to examine the budget itself. Why do we budget? We budget because good planning is essential to good management. Industrial success is frequently directly related to the ability to plan, both tactically and strategically. One of the most important factors in industrial planning is the evaluation of plans in terms of money. A good budget, therefore, is the ultimate in the organization of thought and action. It is

the translation of a plan of action in terms of dollars. The budget must contain plans and facts that can be feasibly and readily translated into action with the greatest possible efficiency. A budget should be considerably more than the compilation of planned expenditures. Inherent in its make-up must be the realization that the budget dollar will produce the required quality control effort in relationship to many other parameters. Efficient utilization of the money to be spent for quality control man power and equipment are high on this list.

In many instances, quality control costs, particularly in the airframe industry, are a fairly large portion of the cost of production. This means that quality control budgets are extremely important in overall company planning. This is not only a reason why budgets are necessary, it is also a reason why the budget should be the best possible effort to express quality control plans objectively.

It can be pointed out that the answer to the question, "Why do we budget?" also contains one of the answers to our problem of how to get the most out of a quality control budget. The budget is a potent form of communicating with management. Quality control people often discuss the problem of selling quality control to management. Any type of selling is a form of communication. The success or failure of the sales program is an excellent index to the efficiency of our communications system. Here then is one way to get the most out of a quality control budget. Everyone understands money. Through the medium of the budget, it is possible to communicate with management in language that is readily understood by everyone. An effective, well planned, logical, quality control budget can open up areas of understanding that are of considerable advantage, both to quality control management and top company management. The answer to a difficult problem often is not in a request for more inspectors or more testing equipment, both of which increase quality control costs. Repeated reliance on this technique is likewise a poor way to sell quality control to management.

The second topic to be considered is, "How should we budget?" In the first place, consideration must be given to company policies, aims and objectives. Production schedules, type of product, sales effort and costs are a few of the things that must be considered. Often both strategic and tactical aspects of these problems must be considered. When long range plans are being considered it is often advisable to establish a series of tactical goals that will bring the strategic aim within easy reach. This means that budgeting should be a systematic effort with ultimate desired aims as well as short term goals.

Careful analysis must be given to the efficient utilization of man power and equipment. By carefully analyzing the production system information can frequently be obtained that can be used as a basis for determining quality control man power and equipment needs. This analysis should consist of two investigations. In the first place, the quality control system must be considered from an internal standpoint, giving due consideration to its duties and objectives. In the second place, quality control should be considered as a part of a much bigger system that usually involves the Engineering, Purchasing, Manufacturing and Quality Control organizations. These analyses must be objective. The quality control effort must be considered in the proper perspective and in the proper relationship with the manufacturing system. The effects of internal quality control policies and aims on this system must be considered. Anyone who has worked as an inspector, or who has even slight knowledge

of quality control, is well aware of the bad effects that poorly conceived, poorly managed quality control can have on schedules and products. The ultimate aim of this analysis, therefore, should be to determine how quality control can be of most service to the production system and the company as a whole.

At this point it seems desirable to begin to consider some specific aspects of budgets. Consequently, the budgeting methods and controls used by the North American Aviation Quality Control Division will be outlined.---

There are several kinds of budgets in our company. This discussion is confined to one budget system which is in actuality two separate efforts. As previously noted, each division at North American Aviation submits a proposal or budget of expenditures each month. This budget is due ten days prior to the period covered. In addition to this, annual forecasts of overhead or burden accounts are made extending the planned costs for one year in advance. Monthly reports are issued comparing budgeted to actual costs and the annual percentage of error is also computed.

One fundamental aspect of getting the most out of a quality control budget is a means of analyzing budgeted effort versus actual effort. It is one thing to plan to spend a certain sum of money, but it is quite another problem to keep actual expenditures within that figure. As a consequence, efforts have been made to provide quality control management with information in the form of administrative controls, that enables corrective action during the budget period rather than after it is too late. As noted previously, a quality control budget is submitted to the financial division each month projecting planned expenditures for the coming thirty day period. The objective obviously is to keep actual expenditures as close as possible to this budgeted figure. As noted above, it is too late to do anything about costs after they have occurred. Consequently, several methods of administrative control are used:

1. When the monthly budget has the final approval of the Director of Quality Control, charts are made for various quality control management people. These charts show their portion of the quality control budget in terms of man power and overtime. These are two of the biggest variables in the budget and were isolated for this reason. The charts are relatively simple with a time scale along the horizontal axis and personnel or overtime hours along the vertical axis. Summary reports are made weekly and actual data is plotted against the target figure. This enables the various managers to correct an unfavorable trend before it is too late.

2. Once each week the entire division personnel effort is summarized on a report that indicates the areas in which the effort can be measured as a ratio of quality control people to production people. The ratio in itself is certainly not the only index of measurement that can be used, but it is useful for comparative purposes and in spotting trends. Quality control activities that cannot be directly related to production are also included in the report which is distributed to the quality control supervisors responsible for various burden centers.

3. A regression chart, Illustration No. 1, is used to compare total quality control dollars to factory direct labor dollars. By

comparing the relationship of the two variables in plotting monthly costs, trend lines and control lines can be applied to this type of chart. For obvious reasons the data and control lines on the accompanying chart are simulated, but will serve to illustrate the usefulness of this type of graphic analysis. For example, the quality control budget is plotted on this type of chart before it is submitted to the Quality Control Director. If the budget exceeds control limits, it is adjusted to be within the proper trends before it is submitted for final approval.

4. Cost of quality control effort in terms of dollars per direct labor hour is also determined and charted. This index is used considerably by Air Force audit people

5. Inspection costs in terms of dollars per pound of airframe produced are also maintained for trend value. This latter type of chart is not an essential part of the budget process, but is certainly valuable in evaluating the differential in cost from model to model.

6. A master over-all trend chart, which will be described later, is used to measure budgeted versus actual performance in terms of past, current and future costs. This chart measures the budget against the trend both as an over-all division effort and by the major elements of the organization.

7. One of the primary methods for controlling budgets is an adequate cost control system. The various functioning elements in the organization must be setup so that expenditures may be broken down and comparisons be made between budgeted and actual performance. In conjunction with the financial division an arrangement has been made so that quality control division is broken down into twenty separate cost centers. The advantages of this are obvious. Individual efficiency can be measured and the reason for unusual or out of control costs can be isolated with the minimum of difficulty and corrective action taken. This is one of the most important ways to control a budget.

There are many ways of attacking the problem of efficiency in a Quality Control Division. In any event, the effort can most readily be measured in terms of money, which brings us back to the budget. The fact that the budget is a management tool has been noted. The following is an illustration of an actual effort made at North American Aviation, Inc., to objectively analyze quality control effort in terms of past, present and future requirements. The objective in this case was to provide the maximum amount of quality control at the lowest possible cost.

Since the organization of a quality control operation is important, from both an internal and external standpoint, Chart No. 2 illustrates the placement of quality control in the company management structure and also illustrates the four basic operations within the Quality Control Division. It may be noted that the Director of Quality Control is in the top management echelon, reporting directly to the President of the company. This is extremely important since the division is independent and can be truely objective in establishing and managing quality standards. The operations of the four sections within the Quality Control Division will be outlined in the subsequent analysis.

In conjunction with the Quality Control Section heads, the Quality Control Director, some months ago, began a program designed to increase the efficiency of quality control efforts to the most economical level possible. It has been noted that by far the greatest percentage of quality control costs are generated by personnel. As a consequence, the problem was attacked first from this standpoint. Quality control performance, in relation to factory direct labor and direct labor dollars, was recapped and charted from 1947 to the present. Trends were thus established and reasons for fluctuation in the load were determined.

It has been noted that the Quality Control Division has been segregated into twenty separate burden centers, or activity groups. Each of these activity groups submit a monthly budget. The actual costs of operating these groups are made available on tab runs so that budgeted and actual performance can be compared. This has been very valuable since it is possible to isolate unusual expenditures and also to determine the relative efficiency of the various groups.

All budgets are submitted on a monthly basis to the Quality Control Analysis Section where they are combined into a total quality control budget and comparisons are made with the established targets. The preparation of a budget by the individual burden center supervisors has also resulted in a tremendous amount of cost consciousness throughout the organization that previously did not exist.

The cost improvement program resulted in detailed objective analysis of existing and future budget plans by each of the four major section heads. These are described in very brief form in the following paragraphs.

The Inspection Department has been working since 1953 on a program that they call "Utilization." Inspection had thus taken a long step toward a solution to the problem of maximum utilization of inspection personnel. The flow of material into an inspection department can seriously interfere with the efficiency of the inspection operation. The product must be released to inspection at a regular scheduled frequency to avoid tremendous peak loads followed by periods of inactivity. Schedule irregularities can also frequently cause inspection overtime when factory overtime is not necessary, thus resulting in a very unfavorable ratio of inspection costs, to direct labor costs.

The utilization program is based on analyses of the time required to perform inspection operations in various portions of the manufacturing area. Consideration is given to the type of manufacturing operation, inspection effort required, schedules, method of manufacture, tooling efficiency and any other pertinent factor. Standards are then established in conjunction with the inspection supervision in the area and the Chief Inspector. Man power budgets in these areas are based, insofar as possible, on the desirable standards. These standards are considered as desirable goals. The system has provided inspection supervision with a management tool that is purely objective and has tended to change a great many "seat of the pants" type of loading rules formerly used. It has enabled the Inspection Department to adjust the working force to best cover manufacturing activities with only the necessary number of inspectors.

It is very difficult to compare laboratory work with traditional indexes; i.e., ratios of lab personnel to production personnel or percent

of lab dollar effort to direct labor dollars. The functions of the laboratory are such that unusual analysis was necessary to determine, as exactly as possible, what the laboratory load should be of the quality control load. Chart No. 3 illustrates the method used to illustrate this effort.

The work load in the laboratory was divided into seven categories. Each category was then analyzed in relation to input requirements and in relation to total laboratory effort. First, take the bottom category on the chart. Supervision and clerical effort was reasonably easy to determine on the basis of total effort since historical information was available on the number of supervisors required to lead the various sections and the number of clerical personnel required per unit section.

Research was next done in the field called, "Process Control and Calibrations." In this instance an actual count was made of the number of processing operations supported by the laboratory. Historical data provided the number of hours required to service, on a periodic basis, the various processing operations. The laboratory maintains surveillance over such processes as heat treat furnaces of all kinds, plating tanks, etching and anodic processes, electrical instrument and calibrations, pressure gauges of all kinds and other equipment in this category. Further research was done to determine engineering requirements for additional or new processing in the future and industrial engineering studies on the amount of equipment to be installed to support future schedules. From the historical data it was possible to determine the number of laboratory people required to support each type of processing operation. This was extended on the basis of future requirements and the load was thus determined.

The laboratory conducts surveys of suppliers who contract for processing work. Once a vendor is approved as a source of subcontracted processing, a recheck is made at six months intervals to determine that the supplier's facilities comply with specifications. In this category a determination was made of the amount of time required to service each vendor and through coordination with the Materiel Division, and observation and analysis of schedules, it was possible to determine the amount of lab effort required for this type of work. It will be noted that there is a slight decline in the effort applied to vendor surveillance toward the end of the chart.

Consideration was next given to a factor known as complexity, or work proportional to the learning curve. This was a difficult problem since work falling into this category is non-routine. The laboratory supplies services to production, engineering and quality control people. A considerable amount of effort is expended toward the examination and solution of shop problems. These problems tend to vary with the complexity of the aircraft being manufactured, and also tend to be heavier at the beginning of a contract than during the latter portions. Also included in this category are such things as receiving inspection support and quality verification testing. After careful searching for a good index, it was determined that certain manufacturing loads move in a similar path to laboratory effort in this field. The study indicated that the correlation of the two curves is sufficiencly close to allow the lab load for this kind of work to be based on a percentage of the manufacturing loads.

The laboratory does a great deal of work in the development area. This effort is primarily in the field of development of process and fabrication methods suitable for efficient manufacturing use. This effort is extremely important and valuable since it frequently results in simplifying complex operations so that they can be feasibly and economically handled in the production function. Analysis revealed that the desired lab development effort should be about 20% of the total lab load.

Construction in the laboratory consists of the manufacturing necessary to provide tools and equipment required by the laboratory. Analysis of this activity indicated that it could be planned on the basis of 14% of the total lab effort.

It will be noted that the laboratory effort was analyzed in terms of hours required per week to support production schedules. This was translated into equivalent personnel with consideration being given to absentee rates and other factors of this kind. Superimposed on the chart are personnel requirements. These requirements have been expressed in terms of the number of technicians that can be acquired per month.

The result of this study provided a readily understandable forecast of quality control requirements in the laboratory area. The analysis is objective and is definitely integrated into the schedule and into the amount of quality control effort required from the laboratory. It provides a useful and flexible tool for future planning.

The Quality Control Analysis portion of total quality control effort was computed on the basis of historical data and future plans and schedules. In three of the groups in the analysis section, this information was readily available. Past experience divulged the number of people required to support the quality control effort in the personnel and budgets field, in the procedures and forms field and the Aircraft Clearance area. Consideration was given to the amount of effort in being and the amount of effort desired.

In the Statistics Section of Quality Control Analysis, it was more difficult to determine a relationship between the requirements for quality control engineers and the total load. The engineers in this group are responsible for developing and installing statistical methods where such methods are applicable and will improve the quality control effort. After some study, it was determined that an initial effort would be made to relate this operation to savings effected as a result of efforts in this field. It was decided that each quality control engineer should provide a savings equivalent to at least four inspectors per year. A target was thus established by which each engineer was evaluated in terms of the number of inspection personnel and dollars. Chart No. 4 illustrates one method of analyzing the effect of such an operation. The chart illustrates the savings realized on one part in one year as a result of the introduction of process control methods. In all other areas where Statistical Quality Control is used, the effort is analyzed in terms of dollars and cents, whenever possible.

A simple question can sometimes create a rather complex analysis. This was brought home when a study was made to determine the number of quality control pilots required to support production schedules during 1956. The question again required an evaluation of costs in the Flight Test Area. It was found that this operation had an affect on such things as insurance and interest rate, in addition to the simple problems of

schedule maintenance. The problem eventually became so complex that it was programmed on a 700 Series Electronic Calculator and the results are just now becoming available. Pilot effort had to be considered in terms of weather, the type of flying required, the number of flights a pilot could fly per day, the availability of aircraft, the time required for flight and the availability of pilots. Results of this study will be used as a load to determine the required number of pilots and its results will provide data that will enable planning for the future in this area. It should be noted here that Inspection Flight Test pilots are charged to direct labor, unlike the rest of quality control.

The results of all of these studies were plotted in the form of a load chart, and a target was established as a result of meetings with the four Quality Control Section heads. The desired percentage of total quality control effort that each of the various groups should comprise was also established. The load chart thus contained past history of the quality control effort, the ultimate goal of the quality control budget and provisions for month-to-month plotting of the effort in relationship to the goal. The target set for reaching the new budget rate was January 1956. In February, the target was met and there is every indication that the goal set will be reached or bettered in the ensuing months. For rather obvious reasons this chart cannot be displayed here. However, some idea of the effectivity of this program can be determined by comparing current performance with performance, as it would have been if the quality control budget had continued on its former trend. The program began in August of 1955. Some idea of the effect of this program can be determined through the following analysis. If the quality control budget for the month of February had followed the trend in existence in July 1955, the Division would have spent $72,314 more than it is now spending. At the same time, careful analysis of the effect of the program has revealed that the quality control effort has not been hampered in any way. If anything, it has improved.

NORTH AMERICAN AVIATION, INC.

QUALITY CONTROL DIVISION

BUDGET & PERFORMANCE CHART

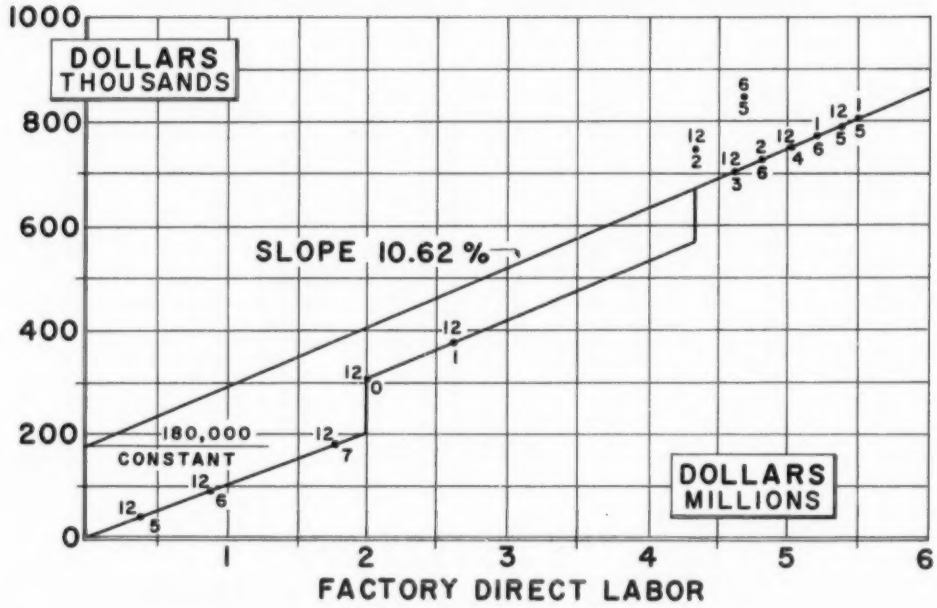
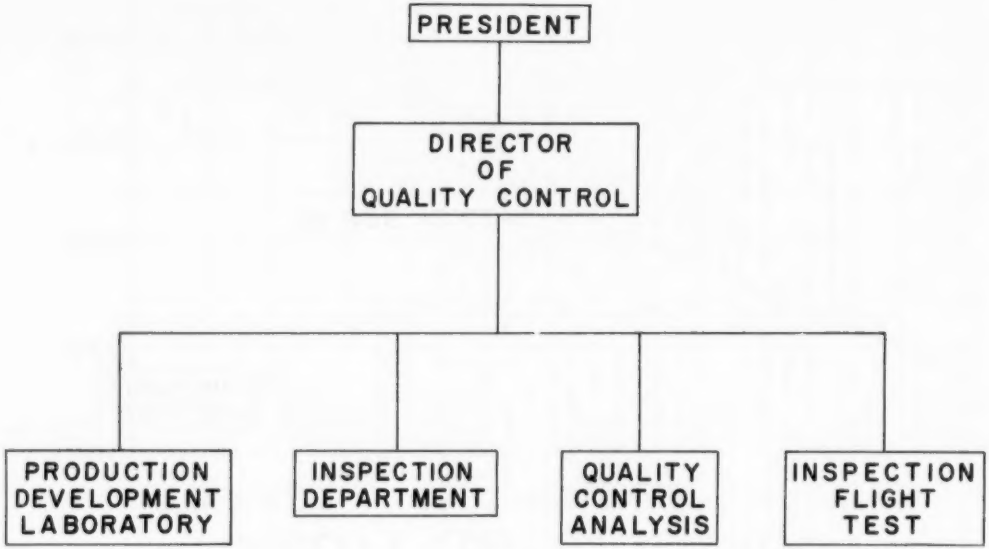


CHART I

QUALITY CONTROL DIVISION
ORGANIZATION CHART



NORTH AMERICAN AVIATION, INC.

CHART 2

NORTH AMERICAN AVIATION, INC.

PRODUCTION DEVELOPMENT LABORATORY

PROJECTED WORK LOAD

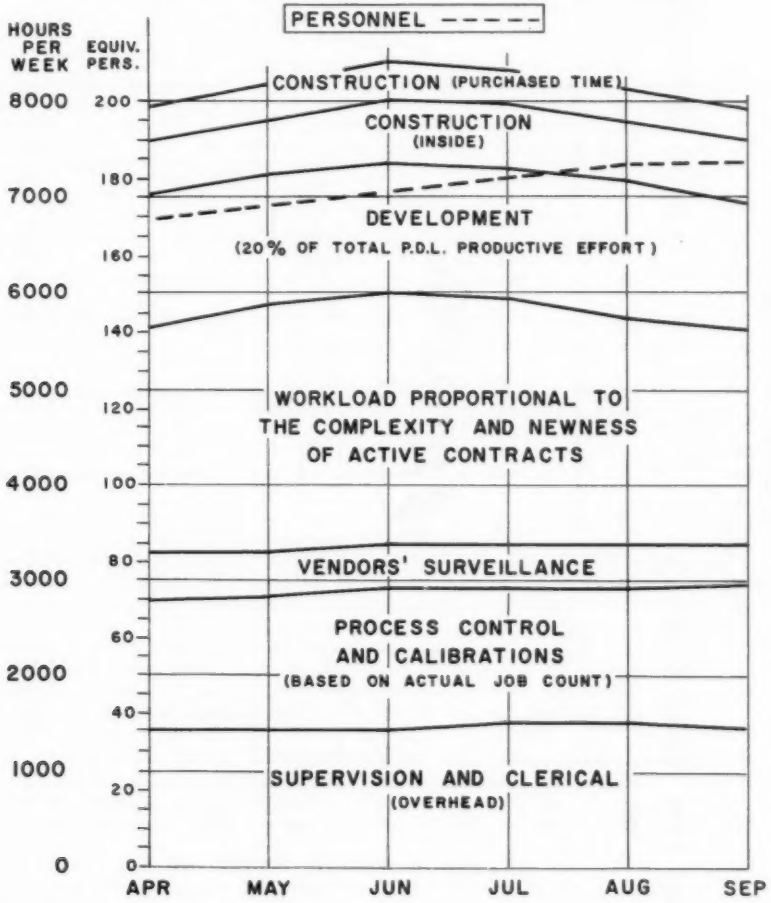


CHART 3

NORTH AMERICAN AVIATION, INC. QUALITY CONTROL DIVISION

CUMULATIVE ACCEPTABILITY RATE

Part Name Valve Body 1954 ——— 1953 - - - Part No. 165-587278-3

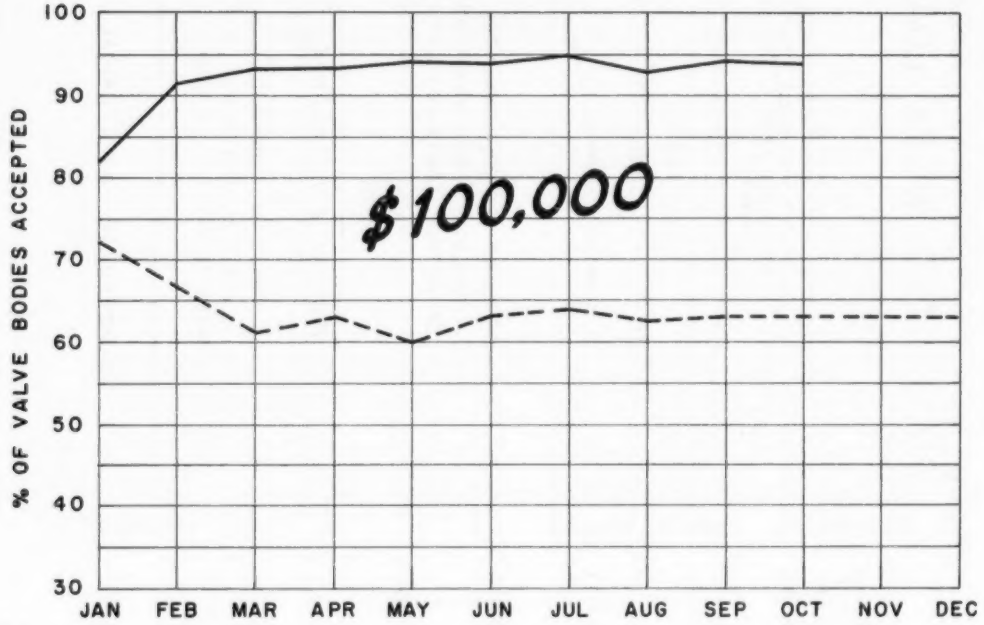


CHART 4

MANAGEMENT USE OF LABORATORY TESTING TO ACHIEVE RELIABILITY

By: Leslie W. Ball
United ElectroDynamics

Scope of the Problem

Technical discussions of Reliability are often guided by the Kelvin principle, "If you can't measure it, you don't know what you are talking about." Consequently, technical studies of reliability often start with an attempt to establish a numerical definition.

Perhaps this management study of reliability should start with this comparable principle, "If you don't know how a laboratory test program will improve sales or profits, you should forget it because you won't obtain the money to do it." It follows, that before discussing how management should use laboratory testing to achieve reliability, we should define the objective of the proposed type of testing in relation to sales and profits. The business purpose, of the type of laboratory testing discussed in this paper, is to increase sales and profits by contributing to customer satisfaction. It will do so by making it more probable that the device being sold to the customer will perform successfully when needed and will do so with a minimum of maintenance.

It is obvious that reliability work done by designers and by the quality control engineers also aims to accomplish the above objective.

In the case of simple mechanical devices such as projectiles, the traditional reliability efforts of design and quality control engineers may be successful in eliminating all causes of unreliability. For products where this is so these two activities will constitute a complete and adequate program.

In the case of more complex devices, a complete reliability program must include work by the designer to minimize unreliability inherent in the initial design and it must include quality control activities to minimize unreliability inherent in the materials, processes and workmanship. But experience has shown, that even when design and quality control activities are extensive and competently handled, not all causes of unreliability will be removed from the first production samples. Experience has shown also, that in addition to the causes of unreliability present in the initial production samples, additional causes occur during the course of production.

Because the reliability inherent in the initial design and manufacture of every single component of a complex system is not good enough for products such as guided missiles, the overall reliability program must include some means for detection of unreliability that is still present in the first production samples.

Because new causes of unreliability occur during the course of production, the overall reliability program must include repetition of the detecting process periodically throughout production.

The main theme of this paper is that progress from the level reliability inherent in today's first class industrial components to the much higher level required for high reliability complex systems, can be

achieved by suitable laboratory evaluation programs skillfully related to the industrial economic system.

The scope of the problem discussed in this paper is (1) an analysis of the causes of unreliability that must be detected by evaluation programs, (2) a definition of the types of laboratory tests that are suitable for detecting the types of error that do occur, and (3) suggestion on ways in which the required evaluation work can be introduced as a mandatory part of the free enterprise commercial system.

General Industrial Structure

Any overall reliability program must be based on an understanding of the general industrial structure through which the system will be produced. In the general case, the United States industrial structure includes these four groups. Materials Vendors who sell to Component Vendors, who sell to Systems Vendors, who sell to Users.

The overall program will require each vendor to do everything possible to pre-assure the reliability of the design, fabrication and handling performed within his own plant. This general requirement for reliability pre-assurance action will be supported by mandatory procedures such as facility surveys, process controls, and in-process inspection.

In addition to the pre-assurance activities within each group, the program should include laboratory testing of each product of each group before it passes on the next group. Thus, each Purchase Order from a Component Vendor to a Materials Vendor should require that a Materials Testing Laboratory certify that the material meets reliability requirements. Each Purchase Order from a Systems Vendor to a Component Vendor should require that a Component Testing Laboratory certify that the components meet their qualification test specifications. Each Purchase Order from a User to a Systems Vendor should require that a Systems Test Laboratory, or Field Test Station, certify that the system meets the performance and reliability requirements contained in the original contract.

In principle, the design and quality control activities within the materials components and system vendors plants must reduce unreliability by every possible means that can be applied before the first samples have been manufactured, while the evaluation programs in the Materials, Component and Systems Evaluation Laboratories must detect all remaining causes of unreliability. We will refer to those causes of unreliability that are present in manufactured items even after much has been done to pre-assure reliability as "Residual Causes of Unreliability."

There are many important reasons why these Residual Causes should be detected as early as possible. For example, if material causes are not detected by a Material Evaluation Program but are found much later during a Component Evaluation Program, or even worse, during a Systems Evaluation Program, then the communication back to the source of trouble will be long and uncertain. Also,if detection is delayed, the amount of wasted manufacturing and lost production time will be excessive. The principle of early detection has been discussed thoroughly and effectively by Dr. A. F. Cone (Ref. 1).

It follows that Management Action to Achieve Reliability by

Laboratory Testing must aim at the ideal that all Residual Causes of Unreliability introduced by the Materials Vendor are discovered by a Materials Evaluation Program, all Residual Causes introduced by a Component Vendor are discovered by a Component Qualification Test Program, and that all Residual Causes introduced by the Systems Vendor are discovered by the Systems Evaluation Program, and that no preventable causes of unreliability are discovered by the User.

Analysis of Residual Causes of Unreliability

The opinions expressed in this paper are based on two decades of analyzing the causes of failure produced by laboratory simulation of service conditions. Looked at from a technical engineering point of view, these causes present a bewildering variety. Looked at from the management point of view, the picture is much more simple. All causes of Residual Unreliability are some form of human error. It follows that management action to detect and remove Residual Causes of Unreliability must be based on a system for detection and control of human errors.

Traditionally, much of the needed system for detecting and controlling human errors is provided by automatic feedback from service experience.

In a traditional product such as an automobile, errors in design or workmanship cause easily recognized service failures. These failures are reported back very quickly through a sales organization with emphatic demands for immediate corrective action. Technically, corrective action is facilitated by a complete and accurate description of the condition under which failure occurred, and by the return of the failed part. Psychologically, corrective action is aided by easy identification of the responsible person and by the certainty of economic punishment if action is not rapid and effective.

Much of this sort of feedback is routine, but sometimes it is dramatic, as for example, the improvement in bridge reliability resulting from the analysis of the failure of the Tacoma Narrows Bridge, or the improvement in resistance to notch brittleness of welded ships that followed the breaking into pieces of several wartime liberty ships.

Now, by contract to more traditional engineering products, consider the case of a part such as a microswitch that is sold to a gyro manufacturer, who sells to a fire control manufacturer, who sells to an aircraft manufacturer, who sells to the Air Force. Suppose further that under battle conditions the part fails to function because of the combined effects of high altitude, low temperature, aircraft vibration, maneuvering acceleration, and gunfire shock. If the plane is shot down, the feedback on the error that caused the failure is lost entirely. If the plane lands, and under static ground conditions the part operates satisfactorily, feedback is still lost. Even if an Air Force maintenance man discovers and replaces a defective sub-assembly, the only feedback may be an unsatisfactory material report stating that under certain unknown conditions, an unidentified part of the fire control system failed. With such meager information, it is not possible to identify the responsible individual, and even if he were reached, he would not possess the facts required to generate corrective action.

In the case of fire control and other complex systems, the challenge to

management is to raise the reliability of every component by orders of magnitude above normal commercial standards, and to do so without the use of the traditional discipline based on service failures.

This is the problem. Is there a solution? I believe that there is a solution. The solution is to be found in the full and skillful exploitation of laboratory testing. This does not mean that the skills of the test engineering are of dominant importance, but rather, that proper management use of these skills is the key to a system in which designers, craftsmen, quality controllers, industrial engineers, industrial psychologists, and even contract writing lawyers, all contribute important parts.

Let us attempt to prove and illustrate this thesis. The control of human errors that cause unreliability has much in common with the control of human errors in civilized communities. In each case, three major steps are required. These steps are (1) indoctrination or preaching of a gospel, (2) evolution of written laws, and (3) evolution of a system of law enforcement that includes a police force equipped for the scientific detection of errors and the identification of their authors.

In this general plan, reliability coordinators are required to preach the basic principles of reliability, and parts application and quality control engineers are required to write a system of laws in the form of specifications and classifications of defects. The job of police detective must be accomplished by experimental physicists or by test engineers working within a management-sponsored system.

The characteristics of the required system are dictated by the types of errors that must be detected and corrected, and by the existing industrial pattern of vendor-buyer relationships. Industrial procurement patterns vary somewhat in different areas and different industries, but the pattern of human errors is universal for all areas and all industries.

Figure 1 presents an over-simplified version of this pattern of errors, and also for each type of error, a method of detection that has been found to be effective. You will note that every one of these detection methods is a form of laboratory testing. Let us examine briefly each type of error.

Note the definition that states, " a component is unreliable until every mode of failure is known, understood, measured and controlled." To illustrate the meaning of this definition, consider that a designer uses a standard type of steel in a tension strut that is subjected to alternating loads. He will know that the mode of failure will be by tensile fatigue,he will understand that the factors affecting failure are stress level, stress concentration and number of cycles, he will make use of measured values from an engineering handbook and he will ensure control by specifying standard chemical, hardness, and dimensional tests. Now suppose that he substitutes a woven wire cable, but fails to realize that a new mode of failure (interwire abrasion) has been introduced. So long as this mode of failure is unknown to the designer, or, being known, is not understood, or, being known and understood, has not been measured, the cable is an unreliable component.

Long experience in design evaluation has shown that in complex

systems subjected to varied environments, lack of knowledge, understanding or measurement of modes of failure is responsible for about half of all new design failures. Therefore in Figure 1, the first error listed is "Mode of Failure unknown."

When all modes are known, the designer still may fail to provide an adequate margin between the strength of the part and the stress that will be experienced in service. This is the familiar "Inadequate safety factor error." In calculating safety factors, a single value is assigned to the strength of the part, and another single value to the maximum service stress.

If the part is such that strength variation from item to item is very small, and if maximum service stress is never exceeded, a moderate safety factor of, say, 1.5, provides for reliability. If this variance is not small, a moderate safety factor will not prevent the low strength items from causing failure. Therefore, a designer, or more accurately, a product engineer, commits an error whenever he uses a fabrication method that produces large strength variance.

The first manufacturing error, "Defective materials or workmanship," is too well known for comment. The next item, "Inspection errors and limitations," is necessary because experience has shown that even 100% inspections do not result in 100% removal of defective items. The word "limitations" is important because for many types of manufacturing error, no non-destructive method of inspection is available.

"Process drift" includes a wide variety of errors, such as machine tool wear, chemical composition changes, and so on. It is important because components for complex systems are qualified by tests on a first article. Unless subsequent production items are identical, the basis for acceptance becomes invalid.

Detection Methods for Residual Causes of Unreliability

Now let us look at the detection methods. To detect unknown modes of failure, the only possible procedure is to subject the component to laboratory simulations of every one of the adverse environments to which it will be subjected in service. If possible, the component must be made to function during the applications of the environment. If the adverse effects of several environments are additive, they must be applied simultaneously. For example, it is generally true that the effects of shock and extreme temperature are additive and therefore they should be applied simultaneously.

To measure the actual value of a safety margin, it is necessary to carry the test to failure. A very elementary example of this is the burst test on hydraulic components. To establish that a specified minimum value has been achieved, a non-destructive proof test may suffice.

To detect excessive variance, it is necessary to perform tests to failure, and to do so in a statistically designed experiment.

Methods for the detection of defective materials and workmanship are as old as industry. Traditionally, visual inspection and gauging methods have dominated, but in the last twenty years a battery of powerful new methods has been provided by experimental physicists. The most

powerful of these methods use x-rays, but ultrasonic, electromagnetic, and many other phenomena provide extremely important solutions to the error detection problem.

Random inspection errors caused by carelessness can be detected simply by repeating the inspection procedure a second time. Errors in the inspector's judgement that he, or even another inspector, would repeat, can be detected by destructive sampling. For example, if an x-ray inspector of castings has been too lenient, test to failure of sample castings can reveal his error. In those cases where available inspection methods are ineffective, destructive sampling must be used. A standard example of this is the inspection of spot welding by testing to failure samples prepared at regular intervals.

The initials S.H A.K.E. represent a method for the detection of inspection errors that has been widely used in complex electronic systems. At first, the word "Shake" was used because the process consisted of applying to each production assembly just enough vibration to cause failure of very defective items such as cold-soldered joints. Any other environment that will produce similar failures can be used. The "burn-in" process for vacuum tubes is another example of a slightly harmful application of a key environment. This method is attractive in that experience has shown that it does reveal large numbers of manufacturing and inspection errors.

An analysis made by the author (Ref. 2) has shown that as the frequency of occurrence of these errors decreases, the method becomes more and more damaging to the reliability of the production units, and therefore it should be used as a destructive sampling test rather than as a pseudo-non-destructive inspection test.

Detection of errors that occur as steady drifts in the properties of a product is the major objective of the quality control engineers in many plants. Familiar examples are process control in electroplating and papermaking.

Cost Control

So far, management use of laboratory testing to achieve reliability has been presented in only qualitative terms. This presentation is satisfactory for determining the type of testing that management should require and the manner in which this testing should be associated with purchase orders as a mandatory requirement. The important question of how much money management should provide to keep on improving reliability can be answered only by quantitative analysis.

The User must establish a numerical value for the operational system reliability objective. This value may be expressed in two radically different ways. In the case of a "one shot" device, such as a missile, it may be stated as a probability of success for a single use. In the case of "continuous use" equipment, such as a radar, the reliability figure may be stated as a mean time to failure for the system.

The Systems Vendor must convert the Users' numerical value into a numerical requirement for each component. Again, this value will be in one of two forms depending on whether the system is a "one shot" or a "continuous use" system. For example, the requirement for a capacitor

in a 3000 component missile system with a system reliability requirement of 85% might be a probability of failure during a single flight of 10^{-5}. The same capacitor when included in a radar might have a requirement of a mean time to failure of 100,000 hours.

If all the items in a component population were structurally identical, then the next step would be easy. It would consist of a laboratory test program to determine the strength distribution curve for the population and would require a relatively small sample.

In practice, there are cases that the population is very homogeneous and the important mode of failure is functional wear out. In these cases the cost of determining reliability is moderate.

In the general case, many of the errors that cause unreliability occur infrequently and at random in the population, and therefore a test performed from a small sample is not representative of the whole population. Also, the variety of ways in which failure may occur is considerable. In a typical case, environments such as vibration and humidity, may provide about ten different important modes of failure.

As a consequence of inhomogeneous populations and multiple modes of failure, the cost of a program that would discover all Residual Causes of Unreliability may be prohibitive. In a previous paper (Ref. 3), an estimate of one billion dollars per year was made for complete testing of a single complex system.

The practical answer to the above problem is for management to do the best that can be done to produce hardware within time and budget limitations and then to continue expenditures on evaluation test programs until satisfactory reliability has been achieved.

In order to get the most reliability improvement for each dollar spent, it is vital that laboratory testing be used as just the first step in a closed loop of detection, analysis, corrective action and re-test.

To make this loop a reality, the following specific actions are required:

1) Improvements and innovations in test methods until all the modes of failure that occur in service are produced under laboratory conditions.

2) Reorientation of test methods stress detection of Residual Causes of Unreliability as opposed to mere simulation of service environments.

3) Increased sampling until causes that are present in only a small fraction of the population are detected.

4) Execution of a thorough program of disassembly and analysis of failed parts so that all causes of unreliability are recognized and understood.

5) Corrective action to prevent recurrence either by Redesign or by Quality Control.

In several specialized papers on Laboratory Testing Technology, the author has presented numerous case histories that demonstrate that the closed loop procedure of detection, analysis and corrective action is practical and effective. In this presentation before the American Society for Quality Control it may be more appropriate to ask what part should the Quality Control Engineer play in the setting up and execution of an overall reliability program in which laboratory testing plays a dominant role.

In the author's opinion, laboratory test engineers and quality control engineers are all part of a single service to management whose objective is to achieve customers' satisfaction by controlling product consistency and reliability. In many companies the quality control organization is so well established that it should be the framework on which a complete independent evaluation service is built. In other companies where a component testing laboratory is better established, the test engineers should acquire thorough knowledge of quality control so that they too can provide a complete independent evaluation service.

Acceptance of the above views would lead to a major increase in the number of functional and environmental test program reports that are presented to ASQC meetings. The complementary occurrence of an increase in quality control papers at the meetings of the American Society for Testing Components is not possible because such a society does not exist.

Conclusion

In conclusion, we will repeat one of the opening thoughts. Namely, that the business objective of Management Use of Laboratory Testing to Achieve Reliability, is Customer satisfaction, and that this objective is the same as that of traditional quality control programs. Therefore, the quality control profession should take an intensive interest in laboratory test programs performed as an evaluation of a Material Vendors product before it is accepted by a Component Vendor, and of a Component Vendors product before it is accepted by a Systems Vendor, and of a Systems Vendor product before it is accepted by a User.

References

Reference 1. Proceedings, Second IRE National Symposium on Quality Control and Reliability in Electronics. "Preventive Testing" by A.F. Cone, Sandia Corporation, Albuquerque, New Mexico.

Reference 2. Final report on Contract SA-04-495-ORD-542 to Redstone Arsenal, Huntsville, Alabama. For detailed analysis, see Progress Report, Part VI.

Reference 3. IRE National Symposium on Quality Control and Reliability in Electronics 1956. "Objectives and Problems of Environmental Testing."

FIGURE 1

RESIDUAL CAUSES OF UNRELIABILITY

Definition - A component is unreliable until every mode of failure is known, understood, measured and controlled.

DESIGN ERROR	DETECTION METHOD (Design Evaluation)
Mode of Failure unknown.	Qualification test program, all environments.
Inadequate safety factor for known mode.	Proof test under simulated service conditions.
Excessive strength variance about mean.	Statistically designed test to failure program.
MANUFACTURING ERROR	**DETECTION METHOD (Quality Control)**
Defective materials or workmanship.	Non-destructive inspection.
Inspection error or limitation.	Reinspection, destructive sampling or S.H.A.K.E.*
Process allowed to drift.	Control of known process parameters.

* S.H.A.K.E. - Slightly Harmful Application of a Key Environment.

USES OF THE PROPAGATION OF ERRORS

Frank W. Wehrfritz
Esso Standard Oil Company

The propagation of error is a mathematical technique for estimating the standard deviation of a function of several variables. Almost all basic courses in applied statistics and quality control introduce the topic, propagation of error, to the engineer or chemist. Usually the introduction takes the form of finding the tolerances to use with a mechanical assembly - say of three rods to be joined end to end. A problem in Grant* illustrates this as follows. Each of three rods is from its own statistically controlled process. This means that each particular rod is expected to be "average" in length and can be expected to deviate from the average in accordance with the process standard deviation, normality is assumed. Upon assembling the three rods, the overall length is expected to be the sum of the three average lengths. The standard deviation around the whole length will be the square root of the sum of the square of each standard deviation. It is clear that the following mathematics has taken place. Designating the three process averages as $\bar{X}$, $\bar{Y}$, $\bar{Z}$, with standard deviations, σ_X, σ_Y, σ_Z, the overall average assembly will be a length L.

$$L = \bar{X} + \bar{Y} + \bar{Z} \qquad (1)$$

The variability surrounding L will be

$$\sigma_L^2 = \sigma_x^2 + \sigma_y^2 + \sigma_z^2 \qquad (2)$$

The square root of equation (2) will give the correct standard deviation to use in estimating the tolerance for the random assemblies of the three parts. The chemist and the engineer frequently has equations which are more complicated than the equation (1). Within the limitations imposed by theory, the propagation of errors can be put to good use in many technical problems. This paper describes the technique and illustrates its use. Suppose that a final calculated quantity, y, is a known function of several variables X_i,

$$Y = f(X_1, X_2, \cdots X_n) \qquad (3)$$

then the variation to be expected in y as a result of the variation in the X_i is

$$\sigma_Y^2 = \left(\frac{\partial Y}{\partial X_1}\right)^2 \sigma_{X_1}^2 + \left(\frac{\partial Y}{\partial X_2}\right)^2 \sigma_{X_2}^2 + \cdots + \left(\frac{\partial Y}{\partial X_n}\right)^2 \sigma_{X_n}^2 \qquad (4)$$

This equation is the propagation of error formula, when the X_i are independent. The deviation of equation (4) involves a Taylors series expansion and is considered exact only for the linear case. It will be remembered from calculus that the Taylors series has a remainder. For the simple linear equation in the foregoing example, there will be no remainder. In the non-linear case, equation (4) will be an approximation and will be best at the average values of the variables and when the standard deviations are relatively small.

* Grant, E. L. "Statistical Quality Control" Chapter 12, Some Statistical Aspects of Tolerances.

In some situations, the X_i are not independent and it will be then necessary to know the degree of correlation expressed as the correlation coefficient for each pairwise X_i which are related. If, for instance, two variables X_1 and X_2 are related via

$$Y = a X_1 + b X_2$$

and pairwise correlation coefficient $\rho_{X_1 X_2}$ is known, then the expected variance for Y is in general

$$\sigma_Y^2 = \left(\frac{\partial Y}{\partial X_1}\right)^2 \sigma_{X_1}^2 + \left(\frac{\partial Y}{\partial X_2}\right)^2 \sigma_{X_2}^2 + 2\left(\frac{\partial Y}{\partial X_1}\right)\left(\frac{\partial Y}{\partial X_2}\right) r_{X_1 X_2} \sigma_{X_1} \sigma_{X_2} \quad (5)$$

and for the above equation becomes

$$\sigma_Y^2 = a^2 \sigma_{X_1}^2 + b^2 \sigma_{X_2}^2 + 2ab\, r_{X_1 X_2} \sigma_{X_1} \sigma_{X_2}$$

Some of the every day problems encountered in the laboratory and plant will illustrate the application of the propagation of error technique.

Example I

Gasoline is a mixture of hydrocarbons (called naphthas) which are proportioned to give certain desirable properties in the finished blend. The vapor pressure of the gasoline is one of these properties and is tailored to fit the seasonal requirements for ease of starting an automobile, that is a high vapor pressure fuel is marketed in the cold months and a low vapor pressure fuel in the summer months.

The vapor pressure of gasoline can be predicted fairly closely by proportioning the vapor pressure of each component according to the per cent to be used in the blend of naphthas. In a blend of six components each used in proportion p_i, with a long run average vapor pressure $\bar{X}_i$, and standard deviation σ_i, the prediction equation is

$$\text{Expected average V.P.} = p_1 \bar{X}_1 + p_2 \bar{X}_2 + \cdots + p_3 \bar{X}_3$$

The variance of this equation is found by applying equation (4)

$$\sigma_{VP}^2 = p_1^2 \sigma_1^2 + p_2^2 \sigma_2^2 + \cdots + p_6^2 \sigma_6^2$$

The table below gives the numerical calculation. The data are coded.

Component X_i	Proportion p_i	Variability $(\sigma_i)^2$	$p_i^2 \sigma_i^2$
1	.15	$(0.60)^2$	.0081
2	.10	$(1.50)^2$	.0225
3	.05	$(0.70)^2$	.0013
4	.17	$(0.13)^2$	.0005
5	.50	$(1.60)^2$	.6400
6	.03	$(5.00)^2$	.0225

Expected variance, σ^2 = .6949

Expected standard deviation, σ = .84

The expected standard deviation was in excellent agreement with the variability in vapor pressures of the initial blends of gasoline found during the several months over which the data were accumulated on each of the six components. The major vapor pressure problems needing technical attention are clearly components 2 and 5. Reduction of variability in these places will bring the initial blends closer to the seasonal target and make the job of finish tailoring the final blend a lot easier.

Example 2

A material balance around a pipe still or other type of processing unit is often expressed as the per cent yield. It is puzzling to the non-statistician to find that yields are greater than 100% some of the time. The expected value is 100% and variation around this value is due to the precision (σ) of the flow meters involved and other causes. Assume a simple splitter tower with only top and bottom product streams and an inlet side stream, all with appropriate liquid flow meters. If each meter has a standard deviation of 1% of the flow being measured, how much of these errors are propagated into the yield equation which is

$$\% \text{ Yield} = \frac{\text{Output}}{\text{Input}} \times 100$$

$$Y = \frac{T(\text{op}) + B(\text{ottom})}{I(\text{nlet})} \times 100$$

If the tower splits the feed stream into equal parts, we expect the top and bottom meters to have a standard deviation of 0.5% and the inlet meters which handles the whole volume to have $\sigma = 1\%$. Applying equation (4),

$$\sigma_Y^2 = \left(\frac{1}{I}\right)^2\sigma_T^2 + \left(\frac{1}{I}\right)^2\sigma_B^2 + \left(\frac{-T}{I^2} + \frac{-B}{I^2}\right)^2\sigma_I^2$$

$$= \left(\frac{1}{100}\right)^2(.5)^2 + \left(\frac{1}{100}\right)^2(.5)^2 + \left(\frac{50}{100^2} + \frac{50}{100^2}\right)^2(1.0)^2$$

$$= \left(\frac{1}{100}\right)^2(.5^2 + .5^2 + 1.0^2)$$

$$\sigma_Y = 1.22\%$$

Daily yield balances are expected to lie within $\pm 2\sigma_Y$ or 2.4% around the balance point of 100%. Therefore, 95% confidence limits of 97.6 to 102.4 can be used as tentative guides for studying the adequacy of meter performance. Daily material balances deviating from these limits would be worth looking into for an assignable cause.

Example 3

There are instances where it is not possible to observe the magnitude of the error of a test method because of the destructive nature of the test. It is desirable to estimate the precision of a single observation since it cannot be replicated. An example of this is a tensile strength test.

Assume flat dumbell shaped specimens breaking at an average pull, P, of 300 lbs. Specimens are nominally 2" wide (W) and 1/8" thick (T). Assume standard devistions for each of these measurements consistent with the equipment available, perhaps from other independent information. These values could be for purposes of illustration, $\sigma_P = 1$ lb. $\sigma_W = .01"$, $\sigma_T = .001"$. The tensile strength formula is

$$T = \frac{\text{lbs. (Pull)}}{\text{in.}^2\ \text{(Width X Thickness)}}$$

$$= \frac{P}{WT}$$

Applying Equation 4, $\sigma_T^2 = \left(\frac{1}{WT}\right)^2\sigma_P^2 + \left(\frac{-P}{WT^2}\right)^2\sigma_T^2 + \left(\frac{-P}{W^2T}\right)^2\sigma_W^2$

substituting the values and solving $\sigma_T^2 = 114.16$

Therefore, the estimated precision of a single observation is

$$\sigma = 12 + \text{psi}$$

The references which follow are recommended for further study. The texts by Deming (1) and Villars (2) develop the theory and provide examples and exercises. The manual by Gore (3) provides an example of estimating the precision of an Inherent Viscosity Measurement. The article by Ferencz (4) has excellent examples of the application of this technique to the problem of cost estimates in the chemical industry. He includes problems where correlation enters the computation. The article by Shewell (5) includes a problem applying the propagation of error to a material balance on a distillation unit, where the overhead product is gaseous and is estimated by difference.

In introducing the section on propagation of errors, Deming (1) indicates that frequently the problem is of "finding the variance of a function in terms of the correlations of the random variables in the function." This is true for chemist and engineer and in all sampling problems. Many times in the physical sciences the propagation of error will describe the whole variance or at least indicate where the larger parts of the problem are.

References

Additional material on the propagation of errors may be found in

(1) Deming, W. E. Some Theory of Sampling, John Wiley and Sons pp 127 - 134

(2) Villars, D. S. Statistical Design and Analysis of Experiments for Development Research pp 330 - 334

Additional examples of the use of the propagation of errors

(3) Gore, W. L. Statistical Methods for Chemical Experimentation Interscience Publishers, Inc. pp 38 - 40

(4) Ferencz, Paul Statistics Can Put More Meaning Into Your Cost Estimates Chemical Engineering, April 1952

(5) Shewell, C. T. Statistics for Everyday Use Petroleum Processing, May 1954

DESIGN OF EXPERIMENT IN METALS PROCESSING

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The statistical design of experiments is, more than ever, being accepted by industry as a requirement for meaningful experimentation. Both in industrial research and manufacturing, the statistical problem is recognized to be more than mere analysis of data. But in spite of this acceptance of experimental design and the familiarity with the statistical methods involved, or perhaps even because of it, there is a tendency to be led into a standardized approach which can miss answering the real problem.

Suppose, for example, a factorial experiment is carried out. It is assumed that this experiment is "designed" in the sense that the number of replications has been determined from the power desirable for the detection of effects from various contrasts, that appropriate blocking has been introduced, etc. In spite of this care of planning, the experiment may be quite unsatisfactory from the standpoint of the question it is supposed to answer, simply because the significance of the factorial contrasts and the estimation of their effects are secondary to this question. The primary interest, for instance, may simply be the ranking of the levels within a classification, that is, choosing the "best" level for operation, and the experiment should have been designed toward that end. Bechhofer [1] , [2] , and others have discussed this important problem.

This paper will consider certain aspects of an important related problem, that of determining the point of maximum (or minimum) yield. The problem will be illustrated by two examples from past experience.

The first illustration is that of determining confidence limits for the value of a single quantitative measurement which produces maximum (or minimum) yield, with special consideration to the requirements for proper design of the experiment. The second illustration is that of determining confidence limits for the point of maximum (or minimum) yield when subject to a linear constraint whose parameters are also determined experimentally.

In the preparation of core sand mixes in the sand casting process, obtaining maximum green tensile strength is important. One of the most obvious variables affecting this strength is the dry mulling time. Prior experience had indicated that maximum strength will occur somewhere between 15 and 60 seconds for a specified type of mix, and it was decided to experiment in this range to determine the maximum--that is, to determine the best mulling time. It was felt that, in this neighborhood of the maximum, the relationship between mulling time and expected strength would be closely approximated by a quadratic function, and in order to be able, furthermore, to test the validity of this hypothesis, four mulling time levels were chosen--15, 30, 45, and 60 seconds, It remained, however, to determine the number of replicates necessary.

Box and Hunter [3] have shown how to determine an exact confidence region for the solution of a set of simultaneous equations. For this example, this method can be used to obtain a confidence interval for the mulling time of maximum strength. The size of this interval will of

course depend on the number of replicates. Suppose, for a given mulling time X, the value of the differential ratio $\left(\frac{a\Delta Y}{\sigma \Delta X}\right)$ is known. Here $\Delta X = |X-X^*|$ and $\Delta Y = |Y-Y^*|$ are the differences in mulling time and strength respectively between the given point on the regression curve (X, Y) and the maximum point (X*, Y*); σ is the residual standard deviation, and a is the standard deviation of the levels of X. It can then readily be shown that the probability β that the derived confidence interval will contain this point X depends further only on the number of replicates r. Furthermore, $\beta(r)$ is smallest when the given point is chosen to be the mean level of X. This probability β, or error of the second kind, may be found from Tang's tables [8]; or conversely, for a desired β and differential ratio, the appropriate number, r, of replicates can be determined.

For the purpose of locating maximum strength, it was then found that four replicates would be sufficient; for, with r = 4, the probability is approximately 10% that the 95% confidence interval will contain the 37-1/2 second mulling time (mean level) when the differential ratio at that time is as high as unity. This corresponds to a ratio $(\Delta Y / \Delta X)$ equal to .003 using an estimated σ = .1 ounce and a calculated $a = 15\sqrt{5}$.

The analysis of variance resulting from the test is shown in Table Ia, and the required estimates and formulas in Table Ib. The confidence limits are finally found to be:

$$X_1 = 32.1 \text{ sec. (lower 95\% confidence limit)}$$

$$X_2 = 37.3 \text{ sec. (upper 95\% confidence limit).}$$

The second example presents perhaps a more common problem, but a more difficult one. It is well known that aging time and aging temperature affect both the tensile yield strength and the elongation of aluminum, but in an opposite manner. Hence, in the development of an alloy, it is desired to determine the aging time and temperature which will maximize the tensile yield, subject to the elongation being equal to or greater than a fixed minimum. The introduction of this constraint, in the form of an elongation requirement, presents an interesting extension to the Box and Hunter approach to confidence regions for the location of a stationary point.

To do this, constraint is assumed to be linear; this is a reasonable assumption for the example in question after a square root transformation of the elongation measurements. The yield strength, on the other hand is suitably fit by a quadratic surface on aging time and aging temperature with linear by linear interaction. Thus if Y is the yield strength and W the transformed elongation, the regression models are:

$$Y = \alpha_{10} + \alpha_{11}P_1 + \alpha_{12}P_2 + \alpha_{13}P_3 + \alpha_{14}P_4 + \alpha_{15}P_5 + \epsilon_1$$

$$W = \alpha_{20} + \alpha_{21}P_1 + \alpha_{22}P_2 + \epsilon_2$$

where ϵ_1 and ϵ_2 are normally distributed with means zero and variances σ_1^2 and σ_2^2 respectively, and where

$$P_1 = (X_1 - A_1)$$

$$P_2 = (X_2 - A_2)$$

$$P_3 = (X_1 - A_1)^2 - A_3$$

$$P_4 = (X_2 - A_2)^2 - A_4$$

$$P_5 = (X_1 - A_1)\ (X_2 - A_2)$$

Here the A's are chosen so that $\sum P_i = 0$ $(i = 1, \cdots, 5)$. Using the Lagrange multiplier λ, the stationary point of E(Y) subject to the constraint $E(W) = W_c$ is found by equating to zero the derivatives of $[E(Y) + \lambda E(W - W_c)]$ with respect to X_1, X_2, and λ:

$$\alpha_{11} + 2 \cdot \alpha_{13} P_1^* + \alpha_{15} P_2^* + \alpha_{21} \lambda^* = 0$$

$$\alpha_{12} + \alpha_{15} P_1^* + 2\alpha_{14} P_2^* + \alpha_{22} \lambda^* = 0$$

$$(\alpha_{20} - W_c) + \alpha_{21} P_1^* + \alpha_{22} P_2^* = 0$$

If σ_1^2 and σ_2^2 are known, then the Box and Hunter approach leads to a $(1 - \alpha)$ confidence region for the stationary point $(P_1^*, P_2^*, \lambda^*)$.

Replacing the α's by their estimates, define

$$d_1 = a_{11} + 2a_{13} P_1 + a_{15} P_2 + a_{21} \lambda$$

$$d_2 = a_{12} + a_{15} P_1 + 2a_{14} P_2 + a_{22} \lambda$$

$$d_3 = (a_{20} - W_c) + a_{21} P_1 + a_{22} P_2$$

Then the confidence region for $(P_1^*, P_2^*, \lambda^*)$ is given by

$$\frac{d_1^2}{\sigma_1^2(d_1)} + \frac{d_2^2}{\sigma_2^2(d_2)} + \frac{d_3^2}{\sigma_3^2(d_3)} = \chi_\alpha^2(3)$$

where $\chi_\alpha^2(3)$ is the α critical value for a χ^2 variate with three degrees of freedom.

The values of $\sigma_i^2(d_i)$ are easily determined in terms of σ_1^2 and σ_2^2 but, generally of course, these variances are not known and must also be estimated from the data. In this example, the variances are estimated by S_1^2 and S_2^2 in the analysis of variance of Tables IIa and IIb, each based on 33 degrees of freedom.

Simply replacing the values of σ_1^2 and σ_2^2 by their estimates S_1^2 and S_2^2 does not, unfortunately, give a variate proportional to an F variate, as would be the case if $\sigma_1^2 = \sigma_2^2$ $(S_1^2 = S_2^2)$. The resulting distrubution is not known. It would seem, however, that this distribution might well be approximated using an approach similar to that of Welch [4] — that is, by an F variate with suitable fractional degrees of freedom. The necessary research on this point is lacking; nevertheless, a good picture of the confidence region can be obtained because the critical value is known to be correct in the limit as the number of degrees of freedom approaches ∞.

By substitution, the boundary of the $(1-\alpha)$ confidence region for $(P_1^*, P_2^*, \lambda^*)$ can be obtained. The envelope of these regions over all values of λ would finally give a confidence region for (P_1^*, P_2^*) for which the confidence is at least $(1-\alpha)$.

The confidence regions for $(1-\alpha)$ equal to 90% and 95% are shown in Figure 1. Table III gives estimated Tensile Yields and Elongations for each of the levels of time and temperature used in the experiment, as well as for the estimated turning point.

The two examples described above are simple by typical industrial experiments in which the objectives are to determine the conditions of optimum response. More general considerations of the problem of response surfaces have been presented by Box and Youle [5], [6], and an excellent exposition has been given by Box in the well known text edited by Davies [7].

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95% Conf. Region
90% Conf. Region
Estimated Point of Maximum
Aging time (hrs.)
Aging Temp. (°F.)
370
340
330
320
6
7
8
9
10
12
13
14

FIGURE 1

TABLE Ia

Analysis of Variance: Green Tensile Strength vs. Milling Time.

Source	degrees of freedom	sum-of-squares	mean-square	F ratio
Replicates	3	.0075	.0025	0.39
Time (linear)	1	.0720	.0720	11.25**
Time (quadratic)	1	.2025	.2025	31.64**
Time (cubic)	1	.0180	.0180	2.81
Error	9	.0575	$S^2 = .0064$	

TABLE Ib

Formulas: Green Tensile Strength vs. Milling Time.

Model: $E(Y) = \mu + \alpha_1 P_1 + \alpha_2 P_2$

$$P_1 = B_1 (X - A_1), \qquad P_2 = B_2 (X - A_1)^2 - A_2$$

(where A_1, A_2, B_1, B_2 are chosen so that $\Sigma P_1^2 = 1$, $\Sigma P_2^2 = 1$, $\Sigma P_1 \cdot P_2 = 0$.)

Confidence limits for location of maximum (minimum):

$$\left[a_1 B_1 + 2a_2 \cdot B_2 \cdot (X - A_1)\right] = \pm \, St_\alpha \sqrt{B_1^2 + 4B_2^2 \cdot (X - A_1)^2}$$

(where a_1 and a_2 are the least-squares estimates of α_1 and α_2 respectively)

$$a_1 = -2.4/8\sqrt{5} \qquad B_1 = 1/15\sqrt{5}$$

$$a_2 = -1.8/8 \qquad B_2 = 1/225$$

TABLE IIa

Analysis of Variance of Tensile Yield Strength

Source	d.f.	sum-of-squares	factorial effects (p.s.i.)
Replicates	3	31.8	
Time (linear)	1	1601.7**	1292
(quadratic)	1	147.0**	-875
(cubic)	1	15.0	
Temperature (linear)	1	1891.1**	3844
(quadratic)	1	35.0**	-302
Interaction (linear-by-linear)	1	18.2*	-169
(non-linear-by-linear)	5	19.7	
Error	33	131.5	

** Significant at 99% level.
* Significant at 95% level.

Mean: 37208
S_1: 998

TABLE IIb

Analysis of Variance of Transformed Elongation.

Source		d.f.	sum-of-squares	factorial effects
Replicates		3	2.13	
Time	(linear)	1	14.41**	-.123
	(quadratic)	1	.05	
	(cubic)	1	.09	
Temperature	(linear)	1	13.73**	-.328
	(quadratic)	1	.77	
Interaction	(linear-by-linear)	1	.05	
	(non-linear-by-linear)	5	1.19	
Error		33	29.65	

Mean: 2.507
S_2: .474

** Significant at 99% level.
* Significant at 95% level.

TABLE III

Aging Time (hrs.)	Aging Temperature (°F) 310	330	350	
4	27800	33100	36500	Tensile Yield (psi)
	9.8	7.8	6.0	Elongation (%)
8	32500	37400	40500	
	8.2	6.4	4.8	
12	35400	40000	42700	
	6.9	5.2	3.7	
16	36600	40800	43200	
	5.6	4.1	2.8	

Estimated best aging time: 10.5 hrs.
Estimated best aging temperature: 339°F.

Expected Tensile Yield: 40735 psi.
Expected Elongation: 5.0%

PREVENTIVE MACHINERY MAINTENANCE AND IT'S VALUE TO MANAGEMENT

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Gentlemen, we who are gathered here to-day are concerned principally with textiles. While there are some bright spots showing on the horizon we cannot ignore the fact that the situation is pretty grim - so grim in fact that a number of manufacturies have either been forced to close or they have closed voluntarily, giving as reason " they can no longer operate profitable." This does not bode well for the future when experienced textile operators feel they can no longer operate and compete with present day markets and when the only alternative is to close up shop and withdraw from competition. Gentlemen, I say to you something must be wrong, so let us try to get a few facts which are pertinent to the questions which inevitably arise concerning such drastic action.

The major reason given is "Foreign Competition." There could be other reasons, however let us examine the statement made for the significances of this declaration most certainly causes apprehension in all quarters and we really must face the facts. Danger signals are up for those who remain in business. It is very true that these statements have been made by reputable persons; persons who have gone to a lot of trouble to collect data, statistics and other information so pertinent to the facts. Reams of paper I would say have been written on the subject however it is not my purpose to go into this matter too deeply and if I may be permitted to say a few things concerning what has been written will be sufficient to bring us up to date.

We probably all know that every Textile Manufacture has protested to the Federal Government. The heads of our Labor Unions have also begged them for a certain amount of protection. Every organization concerned with textiles has voiced their opinion also giving facts and figures and the anticipated help from the Federal Government came in an adverse manner. They have now given Japan preference treatment. To-day we have around fifty percent of the textile market which we can enjoy - if you can possibly call it enjoyment when there is no profit. Evidently our government considers the Primary Textile Industry expendable so they open the doors wider to other countries permitting textiles to flow in like a rampaging river. Our late enemy Japan, in their expanding textile industry, has found a haven for their material at the expense of our mills. Everybody knows that the counterpart of our textile workers in Japan receives only a fraction of his salary. That makes it easy for them to under-sell us - and this is the kind of competition we must meet.

Last Fall and Winter a Canadian Textile Commission went to Japan and visited nearly every textile mill. The survey made by this commission is now a matter of record. Most of us have heard these men speak and report on their survey on different occasions. You can imagine that the news they bring to us is extremely disquieting in as much as the Japanese Textile Industry has been, with few exceptions, completely rebuilt since the war. They were astounded at their remarkable recovery, their machinery is new and modern, of their own make and efficient as can be found anywhere. Their buildings are also new and modern, streamlined for present day production flow and the working methods, handling etc., are up to date which means they can and do turn out material comparable

in quality to any other country and, gentlemen, they actually can bring that material here and under sell any comparable cloth by five percent to forty-seven percent depending on the construction. This, my friends, is what our cotton and synthetic mills must compete with. When things are equal or nearly so, most of the trade will buy the merchandise manufactured at home however, when the differential is so great, the temptation is also too great to pass up bargains especially when the quality is included. If the government cannot equalize or strike a happy balance on the material arriving here, I ask you how it is possible to compete and sell material against a like material from Japan which sells on the average of twenty to twenty-five percent less than our own? I do not see how the government any longer can call this competition or ignore the fact the Primary Textile Industry faces extinction.

Manufacturies are now faced with two alternatives, either bow their heads down in defeat or put their backs to the wall and fight. Most companies have decided to fight and from therein will emerge the strong. It is the survival of the fittest. As a fighter trains to get himself in condition for a gruelling battle, so too, must the Primary Textile Industry gird their loins. They must modernize! They must be able to produce quantity and also with quality! To do this they must be implemented to the highest degree. Machinery must be modern enough to produce efficiently - modern enough to run long periods without break downs. Controls must be applied for economical runs, for efficiency; for quality as well as for quantity and above all, unless sufficiently qualified technical men are available, modernization will be of no avail. The technical know how, the down to earth methods mixed scientifically are the ingredients to a successful product - or a marketable product - just as our engineers plan and build machines for a specific job, so must our technicians be equally cast for specific jobs or we might say experts in their chosen vocation; for instance, we have Doctors, Doctors and Doctors some are general, some are specialists and some are scientists - all very good mind you! Each knowing their own business but would you let a general practitioner operate on your heart - take out a kidney or a lung? I am sure you wouldn't because the results would be fatal. Just because he is a Doctor does not mean he knows everything. The same simple rule also applies to the textile industry as a whole however, some Presidents, Vice-Presidents and Managers think because you are a Textile Engineer, Chemist or what have you, you are a heart specialist, lung specialist, kidney specialist and so on. If we apply the same principal to manufacture of textiles, we would no more think of taking a manufacturing man and put him in charge of dyeing, machine printing, finishing or screen printing or the chemical laboratory. Nor would you turn around and take a converting man and put him in charge of Weaving, Spinning, Preparation or Throwing operations. The results would be disasterous. Some of our textile companies have, to their great sorrow, and found how disasterous and costly mis-casting can be - above all one thing they have never calculated is the demoralizing effect on the employees in general.

This system reminds me of the old army days when you arrived at camp as a shave tail. The Colonel shakes your hand, assigns you to your detail with these remarks," We know you are a little new around here, you have just completed your training however, now we will try and give you the necessary experience to make a good soldier, you will be assigned an old Army Sargeant. He will run things for you so ask his advice before doing anything." The results are: everytime the Sargeant makes a success of something, you get the pat on the back, the advancement and the money.

In the textile business, we have nearly the same condition existing, slightly different mind you and I would like to tell you of just such a disasterous situation. It would be unwise for me to give specific names and location but as I go on some of you will recognize the place. This very big company I have in mind decided to build a twenty million dollar plant incorporated in this plant was the most modern and up to date machinery, methods, laboratories, testing equipment etc., and the personnel for the supervisory positions and on to the top were either engineers or chemists, in all cases graduates of universities (at this point let me make clear that they were marketing a synthetic fibre) Now some of these men were gun powder experts, paint and varnish experts, plastic and cellulose experts but I guess they forgot one important ingredient, just a few good old textile engineers or experienced supervisory personnel. It was not too long after producing that they ran into serious trouble for when their customers called to show them defective yarn, they had to pay sizable claims. The irony of the case was, as is always, the poor little guys away down the line got fired whereas the Executive Vice-President and President should have been fired for rank incompetence in not knowing enough about their detailed operations to fill the positions with experienced personnel. Too often it happens that where $100,000 mistakes are made and covered at the top it is always someone down the line who must pay for it and in most cases it is the machine operator who finds himself in the street or his immediate foreman.

There is another alarming situation I would like to bring before this group as well as to other responsible groups concerned with textiles and that is the future supply or replacement of textile graduates and other technical personnel to the Primary Textile Industry. For three years now, due principally to the very bad publicity and slow down of the Primary Textile Industry, the heads of our textile schools have warned us that student enrollment has dropped off very sharply. It is a recognized fact that, if the Primary Textile Industry is to survive and function in an efficient manner in the years to come, we must absolutely have a continual supply of graduate technicians available. Perhaps we should preach the fact that clothing is a basic staple. The same as food is or oil and coal for heat is or homes for shelter is. Heaven forbid the thought that in the years to come we might be forced to wear simple loin clothes. Think of the exposure. It is my opinion that, no matter how much our own industry is thrust aside, it cannot be ignored too long by any government that we must have technical personnel coming from recognized places of learning - more than that, they must be planned for just as each year we need a certain amount of Doctors, Engineers and other technicians. We should give publicity to the fact that our population is increasing by leaps and bounds each year and because of this continual increase in population, there should be no lack of work and advancement in the textile industry. We should look forward to a bright future therefore I suggest that in order to have a continual flow of graduates to the Primary Textile Industry, the Federal and Provincial or State Governments get together with the individual textile companies and work out a feasible plan of financing potential students in order to arrive at a planned level of yearly graduates. It would be a shame for some of our institutions to eliminate these courses because of lack of students, for surely this will happen in many cases if the students are not enrolling for the various textile courses.

Progressive manufacturies realize that to keep in business, modernization of machinery must be carried out over a period of years. It is

a recognized fact that in textiles a program to this effect is in force and replacement of machines is precalculated for all departments. Some machines must be replaced in five years, others in eight, others in ten years. During this period of usage, these machines must out of necessity be kept in perfect order and I mean just that, perfect running condition. Seconds from these machines must be kept to a minimun and so in these trying times which face us, we have to realize the full gravity of our position that, unless we can compete profitably, our position becomes untenable therefore, we as technicians, must make our contributions to the cause. We must make an earnest endeavor to find means whereby aid can be given the manufacture by various manners wherein we can operate at the highest efficiency. Everyone of us who is interested in textiles for a living is morally obligated in sharing that responsibility, further than that, I firmly believe that any advancement achieved should be shared so all manufactories can stand up to this high jacking of markets by the foreign flow of distress material from beyond our borders. Perhaps some day, if the need is great enough, our manufacturing concerns will stop cutting each other's throats and concentrate on beating the problem facing us. Too many companies actually lose money running certain styles for which they are improperly equipped - why could it not be turned over to a company who is properly equipped and can run that particular style to their advantage? There is an old proverb which might be worth while to repeat "United we can fight, divided we will be defeated."

May I suggest one method wherein we can help and, for all practical purposes we can call this method Preventive Machinery Maintenance. It can be called by other names if we wish - in a way all manufactories practice it to a certain extent but nearly all cases are not controlled. It is criticized at the supervisory level because of their fear of intrusion upon their authority of supervision and by the mechanics themselves because it commits them to a definite program. All along the line it is viewed with suspicion and in order to have it function properly an educational program must be undertaken. Starting in at the top level and working right down to the machine operators, in the end all concerned will have only good to speak of it. It will be appreciated most, perhaps, by the mechanics themselves. This is especially true where there is more than one shift running. Obviously, it should first of all be installed in the Weave Room. Here it will be the most beneficial. It can give life blood in the place most needed because the Weave Room must be considered the heart of the manufacturing division. Everybody realizes to-day that, if we desire a long life, we must submit to a medical examination of the heart periodically. We call it a check up. It is inexpensive because of the peace of mind which comes from the realization we are in good health is the encouragement we need for looking to the future with hope and faith and strength to surmount the every day obstacles.

How many of you have heard remarks in the Weave Room from the loom fixers, "that the guy on the second shift doesn't fix the same as we do." We all know because we are human no two or three fixers on the same section will repair their looms exactly alike. Again how many times we have heard one fellow exclaim, " I have to unfix and make right what the other fellow did." This has been true and is still true to-day.

Pride is a wonderful thing because we must have pride in our well being, our appearance, our daily tasks and because we have this pride we become competitive striving to out pace the other fellow. Mechanics are

also endowed with this spirit of enterprise. Their pride leads them on to assert they are better than the other fellow. Sometimes they are and sometimes they are not - they believe their way is the best way. It even leads some persons to animosities resulting in hatred and revenge and, we know this bodes no good for the company. Pride controlled and directed in the proper channels can become a boon to the individuals as well as the company. Pride in accomplishment as a whole; as a team such as baseball, football, hockey etc., each individual can have pride in the fact he worked for the good of the team and it's eventual success. He can have pride in the part he played to make his set of looms, his section, his weave room, quilling department, throwing department or preparation department come out on top. Pride in the fact his company is one of the successful and top companies.

Let us stop and examine the reason why it is so necessary for any company to-day to have in one manner or another a Preventive Machinery Maintenance Program. (1) To produce efficiently. (2) to produce quality with this efficiency. (3) To produce economically. In order to do all of the above we must be able to operate at top speeds with the minimum of stoppage. Here is where the word Preventive comes into being. We must prevent stoppage and big expensive repair bills by setting up a system of routine checking that will disclose and prevent this trouble before danger points have been reached which cause a major break down. How can it be done? It is quite easy, gentlemen. Before going on let me give to you a striking example of the use of Preventive Machinery Maintenance. Some of you gentlemen who are here to-day owe your life to just such a program because I am very sure a large number flew here by plane. Do you know just how many precautions were taken to bring you here safely? I am sure you don't, but you have come to rely on the airplane as a safe method of travelling and with reason because statistics show there are fewer deaths due to accidents than in automobiles. All the airlines use a method to prevent accidents. They leave little to chance. Their engines are over-hauled after so many miles whether they need it or not to check the wearing out of parts, to prevent any accident and your death. Their method of preventing accidents are highly laudable and are accepted as necessary by everybody to-day. Why can't the textile industry have a comparable program also? Isn't it true some companies have died because of machinery failures? In a sense we can call it an accident; however, to-day it is considered down right stupidity to have a failure due to machinery break downs or machine obsolescence.

(The above material constitutes the first half of Mr. Hauser's talk. The last half was not available in manuscript form at time of going to press. - Nat. Trans. Ch.)